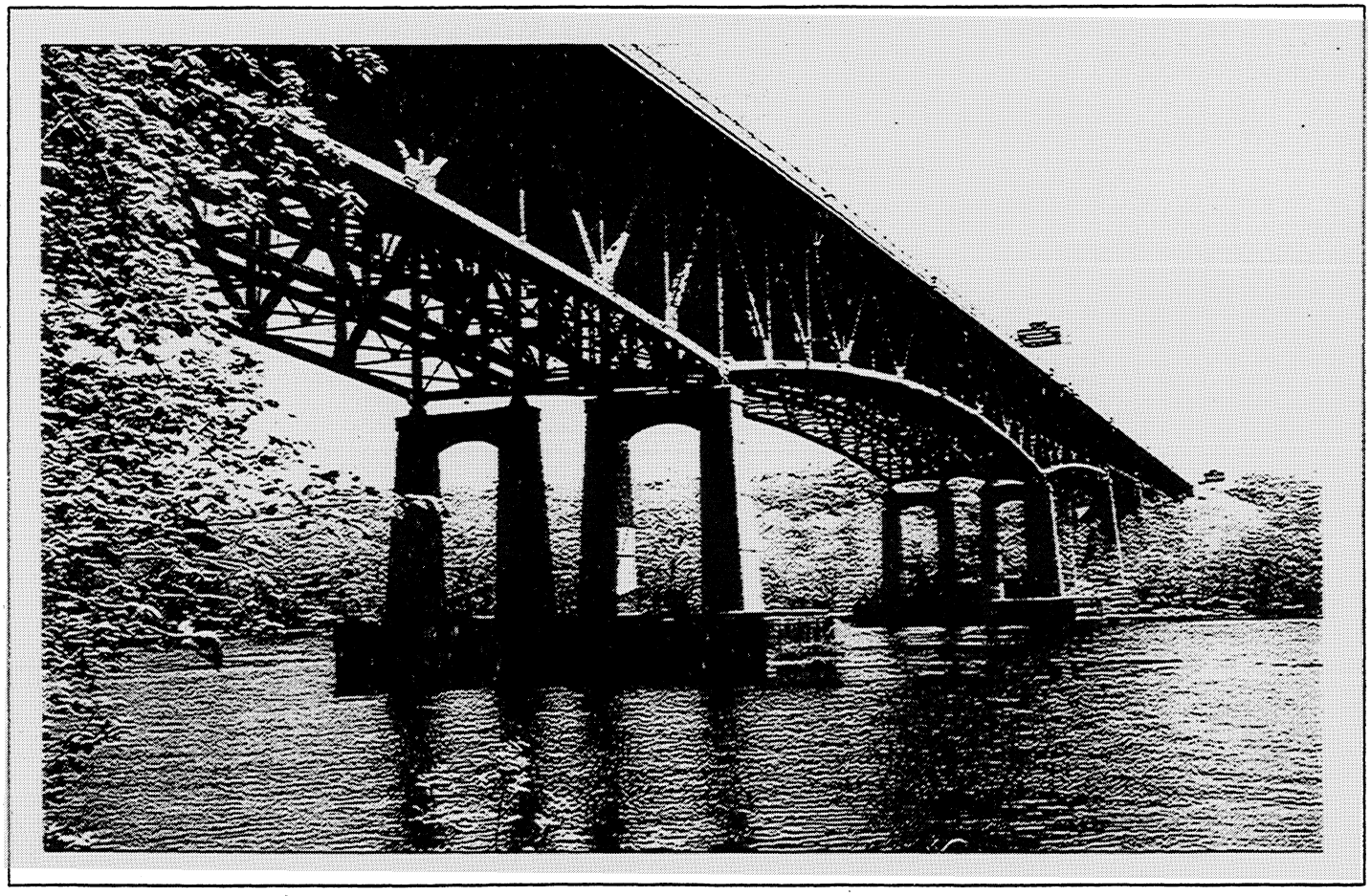
BRIDGE SAFETY ASSURANCE

COLLISION VULNERABILITY MANUAL



New York State Department of Transportation

COLLISION VULNERABILITY MANUAL

NEW YORK STATE
DEPARTMENT OF TRANSPORTATION

STRUCTURES DESIGN AND CONSTRUCTION DIVISION
BRIDGE SAFETY ASSURANCE UNIT

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FOREWORD

The majority of catastrophic bridge failures around the world have occurred for reasons other than those that are primarily condition-based. The collapse of the New York State Thruway Authority's Schoharie Creek Bridge during heavy flooding in April, 1987 is one such example. In order to eliminate or reduce the vulnerability of new and existing bridges to such catastrophic failures, the New York State Department of Transportation (NYSDOT) initiated a comprehensive Bridge Safety Assurance (BSA) Program. This program consists of a multi-step process for identifying potential causes, or modes, of bridge failure and for the subsequent rating of bridges as to the extent of their vulnerability to these failure modes. The Procedure that follows clearly outlines NYSDOT's collision vulnerability assessment. It relates to new bridges, existing bridges and bridges programmed for rehabilitation.

COLLISION VULNERABILITY

MANUAL

FIGURES

SECTION 1 GENERAL

1.1 Introduction

- The New York State Department of Transportation's (NYSDOT'S) **Bridge Safety Assurance (BSA)** program[1] provides a systematic method to reduce the vulnerability of the state's bridges to all potentially significant modes of failure. The program has four phases:

- **Identification** of significant modes of failure,
- **Assessment** of vulnerability of bridges to failure modes,
- **Evaluation** of vulnerable bridges to failure mode,
- **Implementation** of recommendations to reduce vulnerability.

The identification phase has been completed, and the following six failure modes were identified as the most significant in terms of the potential damage they can cause to highway bridges in New York State:

- Hydraulic
- Overload
- Steel structural details
- Collision
- Concrete structural details
- Earthquake

This document focuses on the assessment phase of the BSA program as it relates to **Collision Vulnerability**. Specific details on the assessment process are described and some general evaluation and implementation techniques are also included.

The objective of the collision vulnerability program is to identify the relative vulnerability of the state's bridges to failures due to collision impact damage so that any necessary vulnerability reduction measures can be implemented in an efficient and effective manner.

The objective is accomplished through a series of assessment and evaluation steps that review specific characteristics about individual bridges and result in a **Collision Vulnerability Rating** for a structure. The vulnerability rating describes the likelihood and the consequences of a failure in terms of the corrective actions which are required to reduce the vulnerability and the urgency in which these actions need to be implemented. The rating is used in conjunction with vulnerability ratings from other failure modes to provide a complete understanding of the vulnerability of a bridge.

1.2 Summary

- **Figure 1.1** is a flowchart of the overall collision vulnerability program. The key elements in the program are the assessment, the evaluation and the implementation steps. Each of these steps are briefly described below and more detailed descriptions can be found in subsequent sections and other referenced documents.

Vulnerability Assessment - The vulnerability assessment process is used to determine the relative vulnerability to collision impact damage failure of the entire population of state bridges. The process consists of a classification step and a rating step.

The classifying step uses information such as impact factors, exposure factors, characteristics of traffic and geometrics of the structure and its approaches to evaluate the vulnerability to collision impact damage collapse. The product of this step is a **vulnerability classification score** and a **HIGH, MEDIUM or LOW vulnerability class**. The classification score quantifies the collision vulnerability class for a structure. The vulnerability classes describe the relative potential a structure has for failure due to collision impact damage, and it is used in the rating step to determine the vulnerability rating for a structure.

The rating step is common to all six identified BSA failure modes and it is intended to provide a uniform measure of a structure's vulnerability to failure on the basis of the likelihood of a failure occurring and the consequences of a failure. There are six possible ratings, from 1 to 6, with one being the worst possible rating and 5 being the best. Structures for which this assessment procedure is not applicable are rated 6. These indicate what types of corrective actions are needed and the urgency in which these actions should be implemented. Based on the rating, an interim action such as load posting or closing a bridge may be necessary until an evaluation can be completed and vulnerability reduction measures taken.

Evaluation - The purpose of the evaluation step is to provide a quantitative engineering assessment of a bridge's vulnerability to collision impact damage failure. The results of the evaluation are used, in conjunction with evaluations for other failure modes, to compile a structural integrity evaluation (S.I.E.)[1] report for a bridge and to develop any required vulnerability reduction measures.

Vulnerability Reduction Measures - Implementation - The implementation phase consists of installing or constructing any protective measures, or developing rehabilitation or replacement plans for the structure as the result of an S.I.E. A typical collision vulnerability protection measure for a "thru" type structure would be installation, or upgrade, of bridge railing or barrier. Other possible vulnerability reduction measures might include rehabilitation or replacement or repair of previous impact damage.

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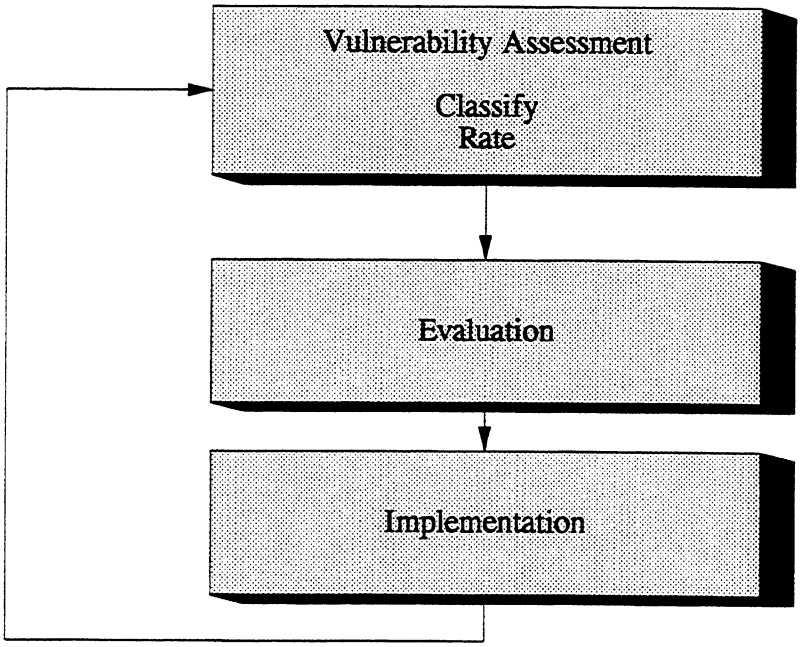
[1] Structural Integrity Evaluation (S.I.E.) - A Structural Integrity Evaluation as defined by the Uniform Code of Bridge Inspection is a detailed engineering evaluation which covers all aspects of the bridge's structural condition and integrity as well as present and future needs to preserve or upgrade the safety and serviceability of the bridge. The evaluation covers all vulnerability factors and failure modes and is required by the Uniform Code of Bridge Inspection for a bridge which has a high vulnerability to a structural failure.

Figure 1.1

Collision Vulnerability Program



SECTION 2 CLASSIFYING

2.1 General - The purpose of the Collision Vulnerability Classifying process is to assess the vulnerability of a structure to a failure caused by collision impact damage. The assessment is based on impact factors, exposure factors, characteristics of traffic and geometrics of the structure and its approaches. The result of this assessment is a classification score which quantifies the potential vulnerability of a structure relative to other bridges in the classifying process and is used to place bridges into a HIGH, MEDIUM, or LOW vulnerability class. These vulnerability classes describe the potential vulnerability of a structure to collision impact damage failure and are used in the vulnerability rating process to characterize the likelihood of failure. The vulnerability classes are defined in Table 2.1. **Figure 2.1** shows an overview of the classifying process, which is divided into two phases, an Inventory phase and a Region Review phase.

The **Inventory phase** is a fully automated process which uses information contained in the Bridge Inventory and Inspection System (BIIS) database to evaluate the vulnerability of the entire bridge population of state owned bridges. This phase will be done in the Central Office Structures Division.

In the **Region Review phase**, the automated scoring of the Inventory Phase is confirmed and all remaining branch factors are scored. Additional factors that are unique to a particular span may be combined to one additional factor score to be included, at the Regions discretion. The final classification score is used to place bridges into HIGH, MEDIUM, or LOW vulnerability classes.

TABLE 2.1 Collision Vulnerability Classes

HIGH: Conditions exist on a structure which create a significant potential for failure due to collision impact damage. Bridges in this class will typically have primary members exposed to direct vehicle, water vessel, or railroad impact. If a protection system exists, it has failed or is inadequate. It is quite likely that during the structure's remaining life it may receive an impact capable of causing failure.

MEDIUM: Conditions exist on a structure which create a recognizable potential for failure due to collision impact damage. Bridges in this class will typically have primary members exposed to direct vehicle, water vessel, or railroad impact. A protection system exists, but may not protect the primary member from severe impact damage, possibly causing failure, and may thereby need to be upgraded or enhanced.

LOW: Conditions exist on a structure which reveal little or no potential for failure due to collision impact damage. These bridge types, while recognized as having primary members susceptible to a collision impact damage failure, have adequate protection to protect against failure.

2.2 Classifying

General - The Inventory process is designed to assess a large population of spans using information contained in the BIIS data files. Because of the size and complexity of the BIIS database, it is possible that some of the data contained in the system will be outdated. The Region Review Phase of the classifying process will confirm and/or update data.

Classification is divided into four branches, as shown in **Table 2.2** and **Figure 2.1**. Each branch is a different scenario for possible collision impact. In each of these scenarios, specific parameters are evaluated and scores are assigned to describe the relative vulnerability of the existing conditions. The scores within each scenario are added and the sum is multiplied by an adjustment modifier to provide an overall score for each scenario.

Collision vulnerability assessment is a repetitive procedure, where each span of each structure is assessed through Branches 1, 2, 3 and 4. For each span, the highest branch score will become the span score. For the entire structure, the highest span score will become the structure score.

Some structures are not vulnerable to any of the four collision scenarios, and therefore receive a rating of 6 (not applicable). An example would be a deck girder structure over a non-navigable waterway.

This procedure is not applicable to certain unique or complicated structures, including, but not limited to arches, tied arches or suspension bridges. These structures will be assessed on an individual basis, because they constitute a very small percentage of the total structures in New York State.

TABLE 2.2 Collision Vulnerability Assessment Classifying Process

Inventory Phase

- Truck On Bridge Collision Assessment
- Truck Under Bridge Collision Assessment
- Water Vessel Collision Assessment
- Train Collision Assessment

Region Review Phase

- Truck On Bridge Collision Assessment
- Truck Under Bridge Collision Assessment
- Water Vessel Collision Assessment
- Train Collision Assessment

Specific details on these assessment processes follow in **Sections 2.2.1 through 2.2.8** and **Figures 2.2 through 2.8**. In the following documentation, **bold print** corresponds to vulnerability factors which are represented by individual boxes or diamonds in the flow charts. An asterisk (*) denotes the various choices that describe the degree of vulnerability. In the Inventory phase, a portion of the questions in

Branches 1-4 have been answered using a program written to pull information out of BIIS. The scoring of these factors should be reviewed during the Region Review phase. Also in the Region Review Phase, all remaining factors should be scored. These factor scores are added to Branches 1-4 respectively. The final Classification score is the score of the highest branch of the highest span.

2.2.1 Branch 1 - Truck On Bridge Collision Vulnerability

General - Branch 1 assesses the vulnerability of the primary members of a span to impact damage sustained from a "truck on bridge" collision. This scenario is applicable only to truss and thru girder bridges that carry truck traffic. Arches, suspension bridges or other bridges with primary members above the roadway shall be evaluated through a Structural Integrity Evaluation. Deck trusses, deck or multi-girder bridges and all other design types with primary members solely below the roadway are not susceptible to truck on bridge collision impact damage and therefore receive a score of zero for Branch 1. A flowchart of Branch 1 is shown in **Figure 2.2**. Details on each factor follow.

Inventory Phase

A. Bridge Type - Is the bridge type a thru-girder, thru-truss or pony truss?

* Yes
* No (If no, Branch 1 Score = 0).

B. Truck Traffic - Does the roadway carry truck traffic?

* Yes
* No

C. Lanes of Traffic (On) - Denotes the number of travel lanes existing on the structure. This includes both bounds of traffic, if two way traffic exists.

* >4, 4, 3, 2, 1

D. Width of Travel Lane (On) - Actual width of travel lane between pavement stripes.

* < 10'-0"
* 10'-0" to 11'-0"
* > 11'-0" to 12'-0"
* > 12'-0"

E. Minimum Vertical Clearance (On) - Indicates the actual minimum vertical clearance on a thru truss between the top of pavement or roadway and the bottom of portal or overhead bracing.

* < 13'-0" to 13'-11" , 14'-0" to 14'-11" , 15'-0" to 15'-11" , > 16'-0" (or not a thru truss)

F. Protective Barriers and/or Railing (On) - Denotes the presence of a barrier or railing system on the bridge to protect primary members.

* None
  - No barrier or railing exists on the structure.
* Substandard barrier or railing
  - A railing or barrier system exists on the structure, but does not meet current standards of AASHTO and New York State. If, however, the existing railing or barrier system provides adequate impact damage protection to exposed primary members, it should be scored as a standard barrier.
* Standard barrier or railing
  - A railing or barrier system exists on the structure which meets all current requirements of AASHTO and New York State.

G. Volume of Truck Traffic (On) (ADTT) - Indicates the current Average Daily Truck Traffic for the highway on the bridge.

* > 5,000 > 2,500 to 5,000 > 1,000 to 2,500 > 200 to 1000 200 or less

H. Bridge Width vs. Highway Width - Termed "necking"; this term is used to describe a difference between the usable roadway width of the approach to the bridge and the curb to curb width or face of rail to face of rail width of the bridge.

The approach width includes the shoulders of the roadway; where shoulders are defined as designed, constructed and maintained flush with the adjacent traffic lane and structurally adequate for all weather and traffic conditions consistent with the facility carried.

* Severe Necking > 10 ft
* Moderate necking 5-10 feet
* Minor necking < 5 feet

* No change

  - The bridge width and the highway width are the same, or the structure is wider than the approaches.

I. Appraisal of Approach Roadway Alignment - Considers the adequacy of the approach roadway alignment in terms of necessitating a reduction in vehicle operating speed.

* Substandard horizontal and/or vertical alignment requiring a substantial reduction (> 10 mph) in vehicle operating speed for safe vehicular travel.

* Substandard horizontal and/or vertical alignment requiring minor reduction of vehicle operating speed (< 10 mph) for safe vehicular travel.

* Acceptable alignments requiring no reduction in vehicle operating speed for safe vehicular travel.

J. Present Wearing Surface (On) - Denotes the type of wearing surface present on the span.

* Steel grating

  - Any steel grating that is either open or filled.

* Timber

  - Any wood or wood block surface.

* Other Surface / None

  - Any concrete, asphalt or other surface not specified above, as well as no wearing surface.

K. Wearing Surface Rating - Indicates the wearing surface condition rating from form TP 350.

* < 3

* 3 or greater

L. Lighting (On)

* No Lighting

  - The roadway on the structure is not illuminated by any type of lighting.

* Lighting

  - The roadway on the structure is illuminated by a light fixture.

Region Review Phase

M. Design Type - This describes the main members exposed to traffic.

* Light Truss
  - Primary members consist of light rolled sections or rods. Primary members exist above the roadway surface.
* Heavy Truss
  - Primary members are made up of heavy rolled sections, built-up sections or multi component sections. Primary members exist above the roadway surface.
* Thru girder
  - A two girder bridge connected by floorbeams attached near the bottom of the girders. The structural deck rests on the floorbeams or on stringers. A substantial portion of the main girders rests above the roadway surface.

N. Posted Load - If the structure is posted for reduced load carrying capacity, score the H20 load posting.

* Not posted (including "R" posting)
* 27 - 36 tons
* 20 - 26 tons
* 12 - 19 tons
* 7 - 11 tons
* 3 - 6 tons

O. Posted Speed Limit - Indicate the posted speed limit in the vicinity of the bridge.

* $\geq$ 55 mph
* 40-50 mph
* 30-35 mph
* $<$ 30 mph

P. Evidence of Previous Impact Damage - Score thru-girder or truss structures which previously have sustained primary member collision impact damage.

* Evidence or documentation exists, indicating primary member collision impact damage.

* No evidence of prior primary member impact damage exists.

Q. Vertical Clearance Warning Signs/Signals - Record the presence of a sign or signal warning the motorist of the vertical clearance for the span.

* Required but not provided.

* Required and provided but not adequate.

* Provided or not required.

R. Horizontal Clearance Warning Signs/Signals - Record the presence of a sign or signal warning the motorist of the horizontal clearance for the span.

* Required but not provided.

* Required and provided but not adequate.

* Provided or not required.

S. Elevated Curb or Sidewalk - Indicate the presence of an elevated curb or sidewalk.

* No elevated curb or sidewalk exits.

* Elevated curb or sidewalk exists (> 1'-0"), or barrier/railing protection exists.

Total Score Branch 1 - The total score for Branch 1 is the summation of the inventory and region review factor scores obtained from within the Branch.

2.2.2 Branch 2 - Truck Under Bridge Collision Vulnerability

General - Branch 2 assesses the vulnerability of primary members of a span to impact damage sustained from a "truck under bridge" collision. This scenario is applicable only to spans which have an under roadway. Spans over navigable waterways are scored in Branch 3 and spans over railroads are scored in Branch 4. Spans not over roadways are not susceptible to truck under bridge collision impact damage and receive a score of zero for Branch two. Branch 2 is divided into two branches: Branch 2A (Superstructure Vulnerability to Truck Under Bridge Collision) and Branch 2B (Pier Susceptibility to Truck Under Bridge Collision). The final Branch 2 score is the higher of Branch 2A and Branch 2B.

2.2.2.1 Branch 2A - Superstructure Vulnerability to Truck Under Bridge Collision

A flowchart of Branch 2A is shown in **Figure 2.3**. Details on each factor follow.

Inventory Phase

A. Under Roadway Feature - Is the feature under a roadway?

* Yes - At least one of the features crossed is an under roadway
* No - No under roadway exists, therefore Branch 2A score = 0

B. Truck Traffic - Does the roadway carry truck traffic?

* Yes
* No

C. Main Member Type - Indicates the primary member design type. To be considered "fracture critical", the span must contain members or tension components of members, whose failure would be expected to result in collapse of the structure.

* Fracture critical deck girder
  - Any two or three non "thru" girder type bridge. One exception is a two or three member system which has been designed with a heavy bracing system to provide an alternate load path. If this bracing system is proven through analysis to provide the necessary redundancy to create an additional load path, the span would not be considered fracture critical.
* Fracture critical deck truss
  - Any deck truss or combination truss where at least a portion of the primary member exists below the deck, i.e. thru girder or truss.

* Other fracture critical main member

  - Other unspecified fracture critical main member in which at least a portion of the primary member exists below the deck.

* Other non-fracture critical main member

  - Other unspecified non-fracture critical main member in which at least a portion of the primary member exists below the deck.

D. Pedestrian Bridge

* Yes

  - This item is scored "yes" if the structure is used exclusively for pedestrian traffic.

* No

  - All structures other than those used exclusively for pedestrian use.

E. Minimum Vertical Clearance (Under) - Indicates the actual minimum vertical clearance from a point on the under roadway to the bottom of the superstructure or other obstruction.

*	< 13'-0"	13'-6" to 13'-5"	14'-0" to 13'-11"	14'-6" to 14'-5"	15'-4" to 15'-3"	> 16'-0" to 16'-0"

F. Structural Redundancy - Structural redundancy is the structure's ability to redistribute its loads within a primary member due to the continuity of the primary members. The end spans of a continuous structure are considered simple for structural redundancy.

* Simple

  - Member is not continuous over either end support.

* Continuous

  - Member is continuous over both end supports.

G. Volume of Truck Traffic (Under) (ADTT) - Indicates the current Average Daily Truck Traffic for the highway under the span.

*	> 5,000	2,500 to 5,000	1,000 to 2,499	200 to 999	< 200

H. Lighting (Under)

* No Lighting
  - The roadway under the structure is not illuminated by any type of lighting.
* Lighting
  - The roadway under the structure is illuminated by a light fixture.

Region Review Phase

I. Posted Speed Limit - Indicate the posted speed limit on the under roadway in the vicinity of the bridge.

* ≥55 mph
* 40-50 mph
* 30-35 mph
* < 30 mph

J. Evidence of Previous Impact Damage - Score structures which previously have sustained primary member collision impact damage.

* Evidence or documentation exists, indicating primary member collision impact damage.
* No evidence of prior primary member impact damage exists.

K. Vertical Clearance Warning Signs/Signals - Record the presence of a sign or signal warning the motorist of the vertical clearance for the under roadway.

* Required but not provided.
* Required and provided but not adequate.
* Provided or not required.

Total Branch 2A - The total for Branch 2A is the summation of all inventory and region review factor scores obtained from within the branch.

2.2.2.2 Branch 2B - Pier Vulnerability to Truck Under Bridge Collision

A flowchart of Branch 2B is shown in **Figure 2.4.** Details on each factor follow.

Inventory Phase

A. Pier Support - Is the over roadway supported by a pier?

* Yes - The structure is a multispan bridge with one or more support piers.
* No - The structure is a single span structure, therefore since no piers exist Branch 2B score=0.

B. Truck Traffic - Does the roadway carry truck traffic?

* Yes
* No

C. Pier Type - Identifies the type of pier exposed to a vehicle collision.

* One or two column pier (steel or concrete)
* Multi-column pier
* Solid pier

D. Protective Barriers and/or Railing (Under) - Indicates the presence of traffic barriers and/or railing in pier vicinity for protection of vehicles using under roadway.

* None
  - No barrier or railing exists for the under roadway.
* Substandard barrier or railing
  - A railing or barrier system exists, but does not meet current standards of AASHTO and New York State. If, however, the existing railing or barrier system provides adequate impact damage protection to exposed primary members, it should be scored as a standard barrier.
* Standard barrier or railing
  - A railing or barrier system exists on the structure which meets all current requirements of AASHTO and New York State.

E. Pedestrian Bridge - Identical score and description to Branch 2A.

F. Structural Redundancy - Identical score and description to Branch 2A.

G. Volume of Truck Traffic (Under) (ADTT) - Identical score and description to Branch 2A.

Region Review Phase

H. Horizontal Clearance - Indicates the least distance from edge of roadway to face of pier.

* < 30 feet without barrier or mound
* < 30 feet with barrier or mound
* 30 feet or greater

I. Weight of Superstructure - In general terms score the weight of the superstructure.

* Light - The superstructure load on the pier(s) is light due to a narrow roadway,pedestrian bridge, lightweight deck or other reasons.
* Moderate - The majority of structures should be considered to have moderate loads on the support piers.
* Heavy - The piers support a large structure with an unusually heavy deck, or a large number of travel lanes.

J. Posted Speed Limit - Identical score and description to Branch 2A.

K. Evidence of Previous Impact Damage - Score pier structures which previously have sustained collision impact damage.

* Evidence or documentation exists, indicating pier collision impact damage.
* No evidence of prior pier impact damage exists.

L. Orientation of Pier(s) - Indicate whether the orientation of the pier(s) with the direction of traffic under the bridge is skewed or parallel.

* Skewed - The pier is orientated at a skew angle to the roadway, thereby exposing the pier to a broadside collision impact hit.
* Parallel - The pier follows the direction of the roadway.

Total Branch 2B - The total for Branch 2B is the summation of inventory and region review factor scores obtained from within the branch.

Total Score Branch 2 - The total score for Branch 2 is the greater of Branch 2A and Branch 2B.

2.2.3 Branch 3 - Water Vessel Collision Vulnerability

General - Branch 3 assesses the vulnerability of a structure to impact damage sustained from a "water vessel" collision. This scenario is applicable only to spans which are over navigable waterways. Spans not over navigable waterways, and spans over navigable waterways where the water traffic is strictly small vessels and pleasure craft, are not susceptible to water vessel collision impact damage and receive a score of zero for Branch three. Branch 3 is divided into two branches: Branch 3A (Superstructure Vulnerability to Water Vessel Collision) and Branch 3B (Pier Susceptibility to Water Vessel Collision). The final Branch 3 score is the higher of Branch 3A and 3B.

2.2.3.1 Branch 3A - Superstructure Vulnerability to Water Vessel Collision

A flowchart of Branch 3A is shown in **Figure 2.5**. Details on each factor follow.

Inventory Phase

A. Navigable Waterway - Is the structure over a navigable waterway?

* Yes - The structure is over a navigable waterway.

* No - The structure is not over a navigable waterway, therefore Branch 3A score = 0.

B. Main Member Type - Indicates the primary member design type. To be considered "fracture critical", the span must contain tension members or tension components of members, whose failure would be expected to result in collapse of the structure.

* Fracture critical deck girder

  - Any two or three non "thru" girder type bridge. One exception is a two or three member system which has been designed with a heavy bracing system to provide an alternate load path. If this bracing system is proven through analysis to provide the necessary redundancy to create an additional load path, the span would not be considered fracture critical.

* Fracture critical deck truss

  - Any deck truss or combination truss where at least a portion of the primary member exists below the deck.

* Other fracture critical main member

  - Other unspecified fracture critical main member in which at least a portion of the primary member exists below the deck.

* Other non-fracture critical main member

- Other unspecified non-fracture critical main member in which at least a portion of the primary member exists below the deck.

C. Movable Span

* Yes

  - This item is scored "yes" if the span is a lift span, bascule span or swing span.

* No

  - This item is scored "no" if the span is not a movable span.

D. Structural Redundancy - Structural redundancy is the structure's ability to redistribute its loads within a primary member due to the continuity of the primary members. The end spans of a continuous structure are considered simple for continuity redundancy.

* Simple

  - Member is not continuous over either end support.

* Continuous

  - Member is continuous over both end supports.

E. Navigation Control - Indicates whether or not an agency controls navigation at the bridge.

* No

  - Navigation is not controlled by an agency.

* Yes

  - Navigation is controlled by an agency.

Region Review Phase

F. Vertical Clearance - Indicates the minimum vertical clearance between the bottom of the superstructure and ordinary water.

* < 35 feet

* 35 - 50 feet

* 51 - 75 feet

* 76 - 100 feet

* 101 - 125 feet

* > 125 feet

G. Type of Vessels Active in Waterway

* Ship

  - Ship classes include bulk carriers, product carriers/tankers, and freighter/container vessels.

* Inland waterway barge

  - Inland waterway barge classes include open and closed hoppers, deck barge and tank barge. Harbor and line haul tugboats are also considered barge vessels.

* Special Vessels

  - Scoring for these vessels is at the discretion of the evaluator. Included here should be ocean-going barges, dredges, offshore industry transports, jack-up boring rigs, barge mounted cranes, Liquefied Natural Gas vessels and naval vessels. Judgement must be exercised in evaluating their influence on vessel collision assessment.

H. Typical Cruising Speed in Vicinity of Bridge - Estimate the typical cruising speed observed for ships and barges in the waterway in the vicinity of the bridge.

* > 20 knots

* 11 - 20 knots

* 3 - 10 knots

* < 3 knots

I. Average Daily Traffic - Estimate the average daily traffic in the waterway under the span. This figure should include only ship and barge traffic and not pleasure craft or other smaller vessels.

* 50 or more vessels per day

* 21 - 49 vessels per day

* 5 - 20 vessels per day

* < 5 vessels per day

J. Evidence of Previous Collision Impact Damage - Indicate whether the superstructure has previously had vessel collision impact damage.

* Evidence or documentation exists, indicating primary member collision impact damage.

* No evidence of prior primary member impact damage exists.

K. Water Elevation - Estimate the variance in water elevation from mean high water to mudline.

* Large variation (> 5 foot)

* Moderate variation (1 - 5 feet)

* Little variation (< 1 foot)

Total Branch 3A - The total for Branch 3A is the summation of inventory and region review factor scores obtained from within the branch.

2.2.3.2 Branch 3B - Pier Vulnerability to Water Vessel Collision

Branch 3B assesses the vulnerability of the pier(s) of a structure to impact damage sustained from a "water vessel" collision. This scenario is applicable only to spans over navigable waterways. Spans not over navigable waterways or with no piers in the navigable waterway are not susceptible to water vessel collision impact damage and receive a score of zero for Branch 3B. A flowchart of Branch 3B is shown in **Figure 2.6**.

Details on each factor follow.

Inventory Phase

A. Navigable Waterway - Is the structure over a navigable waterway?

* Yes - The structure is over a navigable waterway.

* No - The structure is not over a navigable wasterway, therefore Branch 3A score = 0.

B. Movable Bridge - Identical score and description to Branch 3A.

C. Navigation Control - Identical score and description to Branch 3A.

D. Structural Redundancy - Identical score and description to Branch 3A.

Region Review Phase

E. Pier in Navigable Waterway - Indicate whether or not there is a pier in the navigable waterway. If there is no pier in the navigable waterway, then the Branch 3B score is zero.

* Yes - Skewed to flow

* Yes - Parallel to flow

* No - No pier in navigable waterway

F. Horizontal Clearance - Score the horizontal clearance as adequate or inadequate based on the largest vessel using the channel. Adequate channel width is considered to be the length of the largest vessel length to typically pass under the structure.

* Inadequate

* Adequate

G. Pier Protection System - Identify whether or not a pier in a navigable waterway has some form of pier protection.

* None

* Fender system

  - Any type of fender system designed to absorb impact energy and forces including but not limited to: Timber fenders, rubber fenders, concrete fenders and steel fenders.

* Pile supported system

  - Energies associated with vessel collision are absorbed by plastic deformation and crushing of pile structure. After collision all or part of the pile structure usually requires replacement.

* Dolphin Protection

  - Circular cells typically constructed of driven steel sheet piling, filled with rock or sand, and topped by a concrete cap. Usually surrounded by timber or rubber fenders to prevent metal to metal contact.

* Island protection system

  - Sand or rock core protected by outer layers of heavy rock armor to provide protection for the island against waves. Islands generally provide the highest level of ship collision protection.

* Floating protection system

  - Used where water is too deep for other type of pier protection. Vessel energy is absorbed with small forces and large deformations using high strength cable tension members.

H. Type of Vessels Active in Waterway

* Ship - Identical score and description to Branch 3A.

* Inland waterway barge - Identical score and description to Branch 3A.

* Special Vessels - Scoring for these vessels is at the discretion of the evaluator. Included here should be ocean-going barges, dredges, offshore industry transports, jack-up boring rigs, barge mounted cranes, Liquefied Natural Gas vessels and naval vessels. Judgement must be exercised in evaluating their influence on vessel collision assessment.

I. Typical Cruising Speed in Vicinity of Bridge - Estimate the typical cruising speed observed for ships and barges in the waterway in the vicinity of the bridge. Score same as Branch 3A.

J. Average Daily Traffic - Estimate the average daily traffic in the waterway under the span. This figure should include only ship and barge traffic and not pleasure craft or other smaller vessels. Score same as Branch 3A.

K. Evidence of Previous Impact Damage - Score piers which previously have sustained collision impact damage.

* Evidence or documentation exists, indicating pier collision impact damage.

* No evidence of prior pier impact damage exists.

L. Horizontal Channel Layout

* Poor
  - Channel meanders or is dangerous during poor visibility conditions.

* Fair
  - Channel has some horizontal curvature making it more difficult for a vessel to negotiate the passage.

* Good
  - No channel difficulties of any consequence.

M. Water Currents - Indicate, based on judgement, the strength of any cross currents common in the channel.

* Strong cross currents common

* Moderate cross currents common

* Little or no cross currents

Total Branch 3B - The total score for Branch 3B is the summation of inventory and region review factor scores obtained from within the branch.

Total Score Branch 3 - The total score for Branch 3 is the greater of Branch 3A and Branch 3B.

2.2.4 Branch 4 - Train Under Bridge Collision Vulnerability

General - Branch 4 assesses the vulnerability of primary members to impact damage sustained from a train collision. This scenario is applicable only to spans crossing railroad tracks. All other spans receive a score of zero for Branch 4. Branch 4 is divided into two branches: Branch 4A (Superstructure Vulnerability to Train Collision) and Branch 4B (Pier Susceptibility to Train Collision). The final Branch 4 score is the higher of Branch 4A and Branch 4B.

A flowchart of Branch 4A is shown in **Figure 2.7**. Details on each factor follow.

2.2.4.1 Branch 4A - Superstructure Vulnerability to Train Under Bridge Collision

Inventory Phase

A. Feature Under - Is the feature under a railroad?

* Yes - Feature under is a railroad
* No - Feature under is not a railroad

B. Main Member Type - Indicates the primary member design type. To be considered "fracture critical", the span must contain members or tension components of members, whose failure would be expected to result in collapse of the structure.

* Fracture critical deck girder
  - Any two or three non "thru" girder type bridge. One exception is a two or three member system which has been designed with a heavy bracing system to provide an alternate load path. If this bracing system is proven through analysis to provide the necessary redundancy to create an additional load path, the span would not be considered fracture critical.
* Fracture critical deck truss
  - Any deck truss or combination truss where at least a portion of the primary member exists below the deck.
* Other fracture critical main member
  - Other unspecified fracture critical main member in which at least a portion of the primary member exists below the deck.
* Other non-fracture critical main member
  - Other unspecified non-fracture critical main member in which at least a portion of the primary member exists below the deck.

C. Minimum Vertical Clearance (Under) - Indicates the actual minimum vertical clearance from the highest rail to the bottom of the superstructure or other obstruction.

* < 20 ft, 20'-0" to 20'-11", 21'-0" to 22'-0", > 22 ft

D. Structural Redundancy - Structural redundancy is the structure's ability to redistribute its loads within a primary member due to the continuity of the primary members. The end spans of a continuous structure are considered simple for structural redundancy.

* Simple
  - Member is not continuous over either end support.
* Continuous
  - Member is continuous over both end supports.

Region Review Phase

E. Evidence of Previous Impact Damage - Score structures which previously have sustained primary member collision impact damage.

* Evidence or documentation exists, indicating primary member collision impact damage.
* No evidence of prior primary member impact damage exists.

Total Branch 4A - The total for Branch 4A is the summation of inventory and region review factors scores obtained from within the branch.

2.2.4.2 Branch 4B - Pier Vulnerability to Train Under Bridge Collision

General - Branch 4B assesses the vulnerability of the pier(s) of a structure to impact damage sustained from a train collision. This scenario is applicable only to spans over railroad tracks. Spans not over active railroad tracks are not susceptible to train collision impact damage and receive a score of zero for Branch 4B. A flowchart of Branch 4B is shown in **Figure 2.8**.

Inventory Phase

A. Feature Under - Is the feature under a railroad?

* Yes - Feature under is a railroad
* No - Feature under is not a railroad

B. Structural Redundancy - Structural redundancy is the structure's ability to redistribute its loads within a primary member due to the continuity of the primary members. The end spans of a continuous structure are considered simple for structural redundancy.

* Simple
  - Member is not continuous over either end support.
* Continuous
  - Member is continuous over both end supports.

Region Review Phase

C. Horizontal Clearance - Indicate the least distance from centerline of track to face of pier.

* < 10 feet
* 10 feet to 15 feet
* 16 feet to 20 feet
* > 20 feet

D. Crashwall

* Not present and required
* Present and inadequate
* Present and adequate or not required.

E. Evidence of Previous Impact Damage - Score piers which previously have sustained collision impact damage.

* Evidence or documentation exists, indicating pier collision impact damage.
* No evidence of prior pier impact damage exists.

Total Branch 4B - The total score for Branch 4B is the summation of inventory and region review factor scores obtained from within the branch.

Total Score Branch 4 - The total score for Branch 4 is the greater of Branch 4A and Branch 4B.

2.2.5 Classification Score

Collision Vulnerability Class - Once all four branches have been scored, the classification score becomes that of the highest branch. Bridges are then placed into a collision vulnerability class on the basis of the ranges of the classifying scores shown in Table 2.3.

TABLE 2.3 Vulnerability Classification Score Ranges for Collision Vulnerability Classes

CLASSIFICATION SCORE	VULNERABILITY CLASS
> 40	HIGH
25 - 55	MEDIUM
< 40	LOW

Overlapping ranges are used to provide the evaluator with some discretion in assigning a vulnerability class. The vulnerability class coupled with the classification score determine the order in which structures should be progressed to the next step in the assessment process, vulnerability rating. Structures in the HIGH class have first priority, MEDIUM second and LOW third priority. Within a class the classification scores establish priorities.

A field visit to the bridge may be necessary for completing the classifying step. It is important that all of the parameters in the process are addressed and the evaluating engineer should make an effort to obtain all of the necessary data to complete these evaluations.

2.2.6 Protective Countermeasures

- An ancillary function of the classifying step is to identify any bridges that have potentially catastrophic conditions and to recommend repairs to safeguard against a failure. If on a field visit, the field evaluation the engineer should look for potentially catastrophic conditions which could lead to the collapse of the structure. If any potentially catastrophic conditions are found, appropriate interim protective measures should be recommended to safeguard against a failure until a more detailed evaluation and remediation plan can be developed. These recommended countermeasures should be noted on the bottom of the summary sheet and the Regional Structures Engineer should be notified to assure that these measures are implemented. If necessary, bridge flagging procedures should be used. The countermeasures recommended at this point are intended to be interim fixes aimed at protecting the bridge until more permanent remedial measures can be designed and constructed.

The recommended protective countermeasures should not be considered in the classifying process until they have actually been installed. The classifying process should be continued and the bridge evaluated taking into account only the existing conditions. Once the recommended fixes are installed, the bridge can be re-evaluated and re-classified.

FIGURE 2.1

COLLISION VULNERABILITY CLASSIFYING PROCEDURE

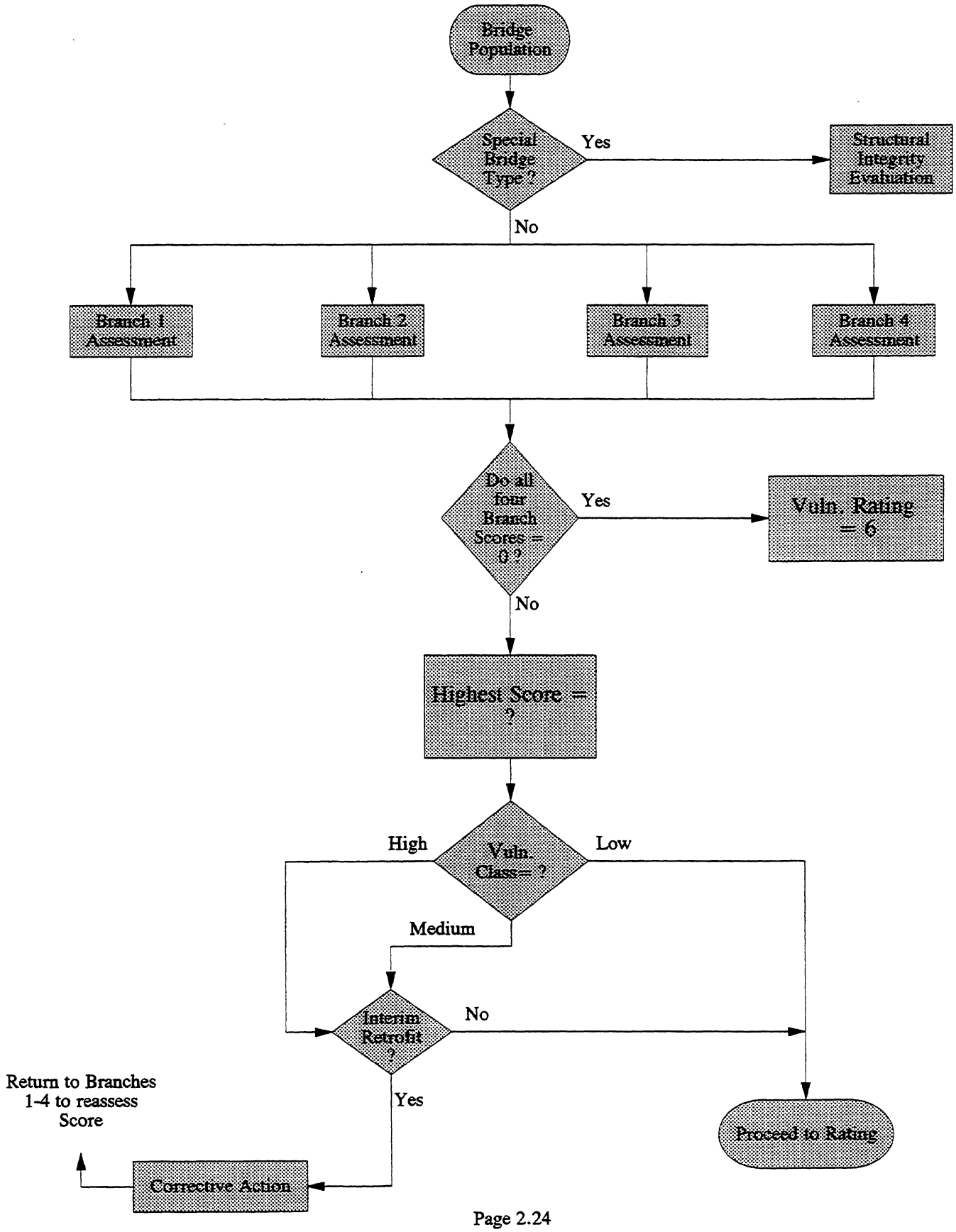
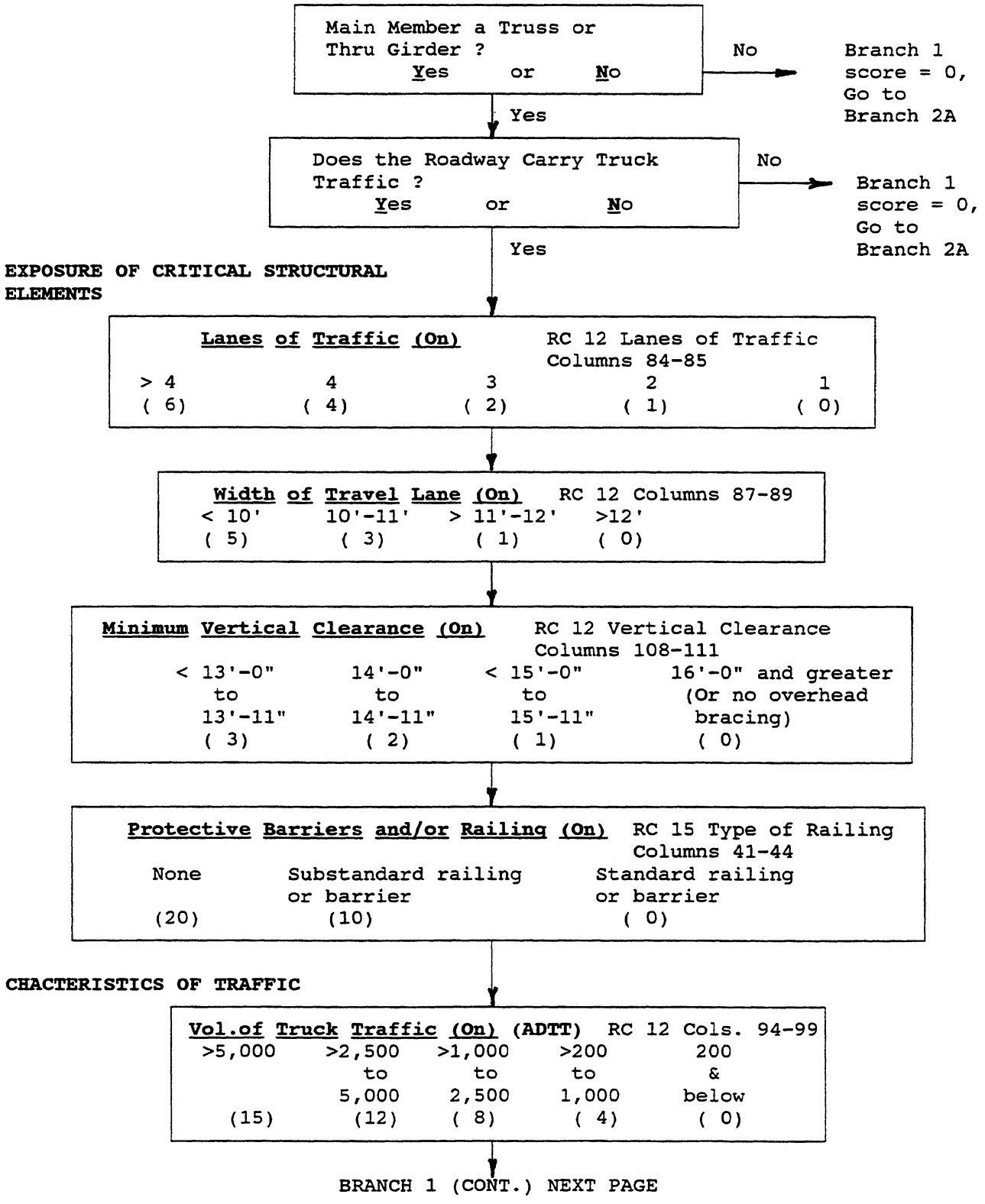


FIGURE 2.2

BRANCH 1 - TRUCK ON BRIDGE COLLISION VULNERABILITY



BRANCH 1 (CONT.) NEXT PAGE

Figure 2.2 (Cont.)

GEOMETRICS OF HIGHWAY & HIGHWAY FEATURES

Bridge Width vs. Highway Width
RC 02 Curb -to-Curb Width Cols. 47-50
RC 02 Roadway Approach Width Cols. 39-41

Severe necking > 10 ft	Moderate necking 5-10 ft	Minor necking <5 ft	No change
(10)	(6)	(2)	(0)

Appraisal of Approach Roadway Alignment RC 03 Col. 21

Substandard horiz. &/or vertical alignment requiring Substantial reduction of vehicle operating speed	Substandard horiz. &/or vertical alignment requiring Minor reduction of vehicle operating speed	Acceptable alignments requiring No reduction of vehicle operating speed
(10)	(5)	(0)

Present Wearing Surface (On) RC 15 Col. 57-58

Steel grating open or filled	Timber	Other surface
(5)	(3)	(0)

HIGHWAY FEATURES

Wearing Surface Rating TP 350 Col. 19

< 3	3 or higher
(5)	(0)

Lighting (On) RC 03 Light Fixtures On Col. 47

No lighting	Lighting
(2)	(0)

REGION REVIEW PHASE

Design Type RC 15 Design type Col. 17-18
Coding 11, 15, 18-21

Light Truss	Heavy Truss	Thru girder
(10)	(4)	(0)

BRANCH 1 (CONT.) NEXT PAGE

FIGURE 2.2 (CONT.)

IMPACT OF COLLISION

Posted Load		RC 06 Col. 27-28			
Not Posted	27-36 Tons	20-26 Tons	12-19 Tons	7-11 Tons	3-6 Tons
(8)	(6)	(4)	(3)	(2)	(0)

Posted Speed Limit			
≥55 mph	40-50 mph	30-35 mph	<30 mph
(8)	(4)	(2)	(0)

CHARACTERISTICS OF TRAFFIC

Evidence of Previous Impact Damage	
Evidence or Documentation exists revealing prior collision impact damage	No evidence of prior impact damage exists
(15)	(0)

GEOMETRICS OF HIGHWAY & HIGHWAY FEATURES

Vertical Clearance Warning Signs/Signals		
Not Provided	Provided but not Adequate	Not Required/ Provided
(2)	(1)	(0)

Horizontal Clearance Warning Signs/Signals		
Not Provided	Provided but not Adequate	Not Required/ Provided
(2)	(1)	(0)

Elevated Curb or Sidewalk	
No Elevated Curb or Sidewalk, and no Barrier or Railing	Elevated Curb or Sidewalk exists, or Barrier/Railing protection exists
(4)	(0)

BRANCH 1 SUBTOTAL = _____

TOTAL SCORE BRANCH 1 = SUBTOTAL X 0.8 = _____

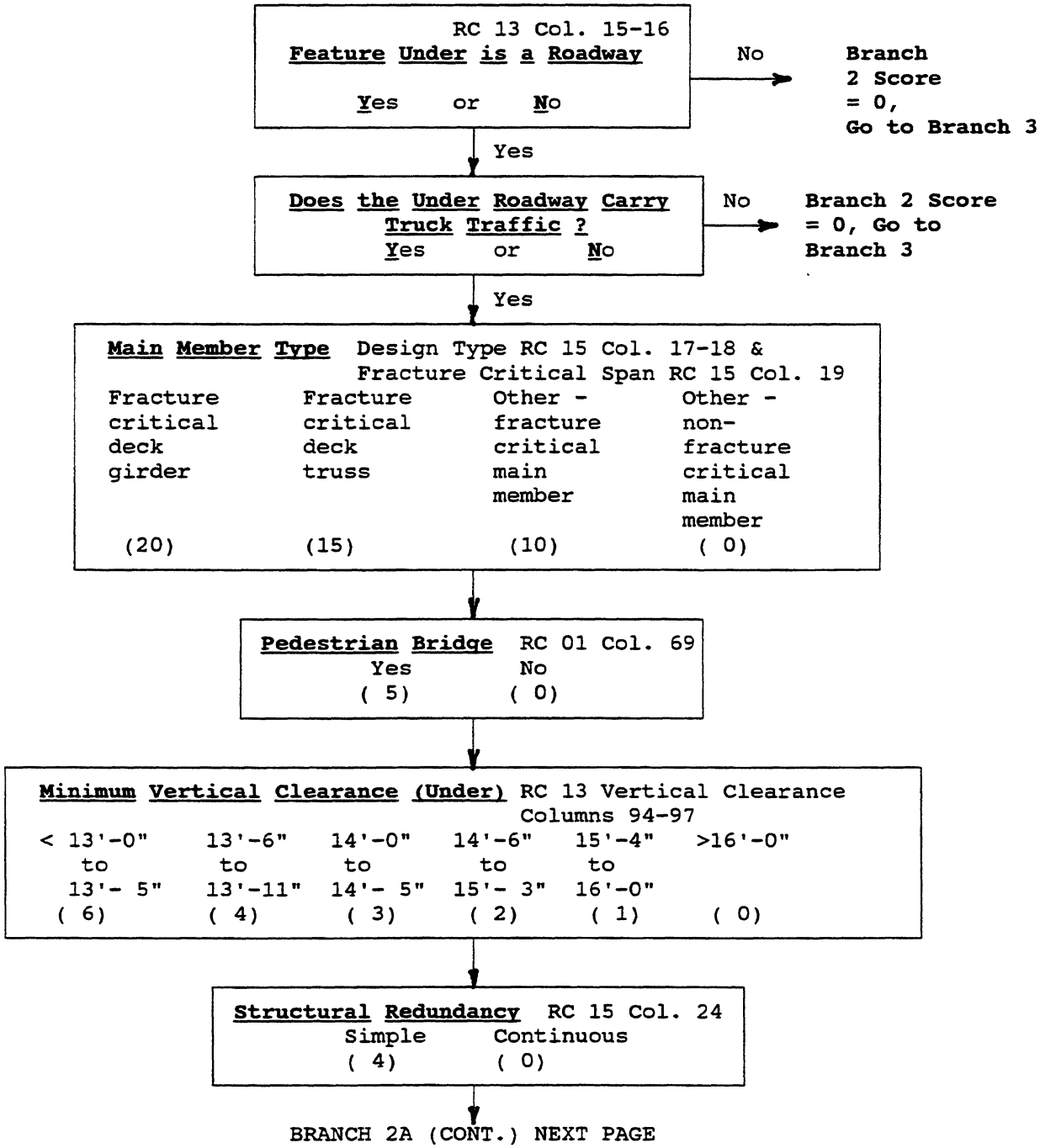
Go to Branch 2

FIGURE 2.3

TRUCK UNDER BRIDGE COLLISION VULNERABILITY

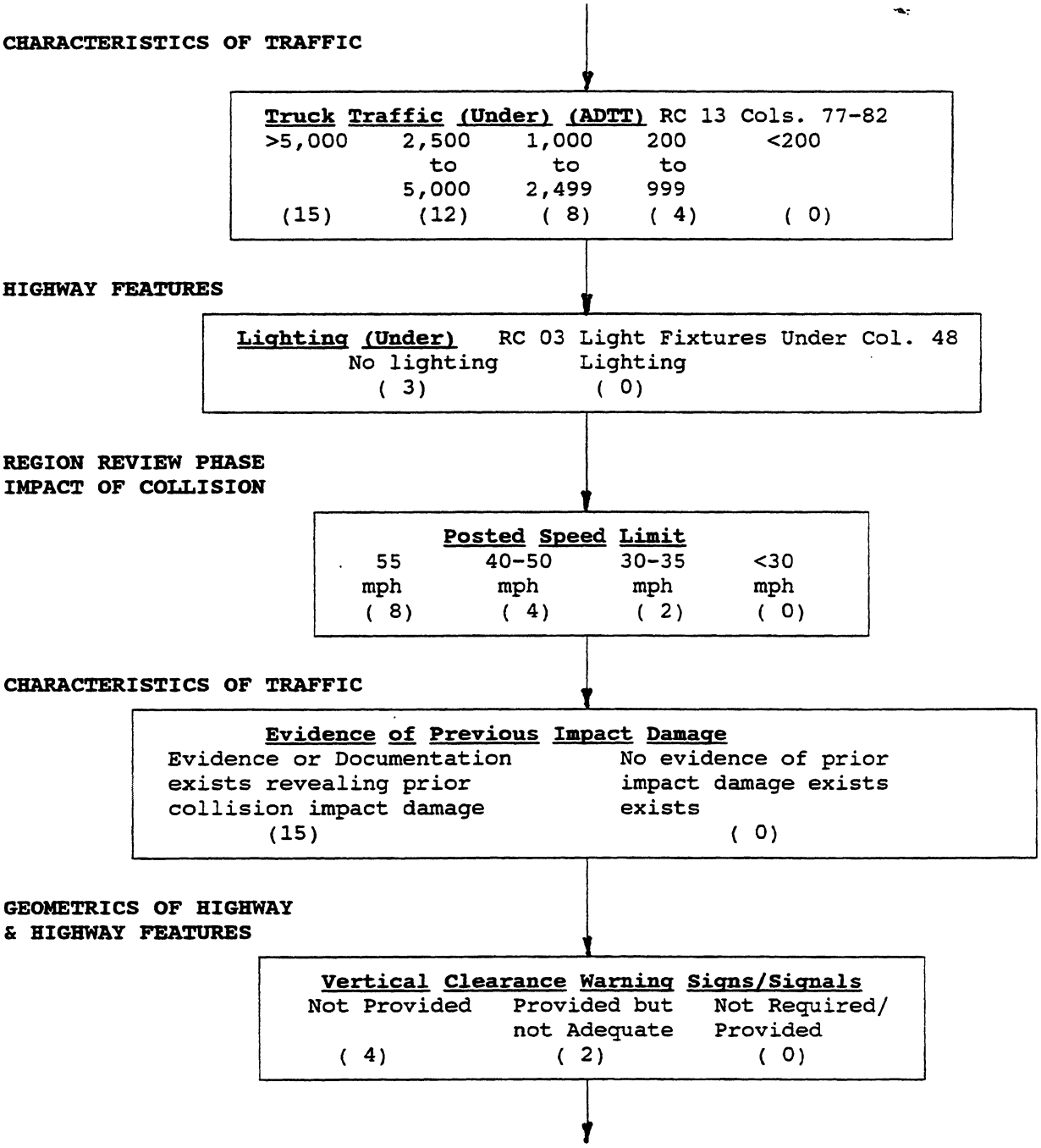
BRANCH 2A - SUPERSTRUCTURE VULNERABILITY TO TRUCK UNDER BRIDGE COLLISION

INVENTORY PHASE



BRANCH 2A (CONT.) NEXT PAGE

FIGURE 2.3 (CONT.)



BRANCH 2A SUBTOTAL = _____

TOTAL SCORE BRANCH 2A = SUBTOTAL = _____

Go to Branch 2B

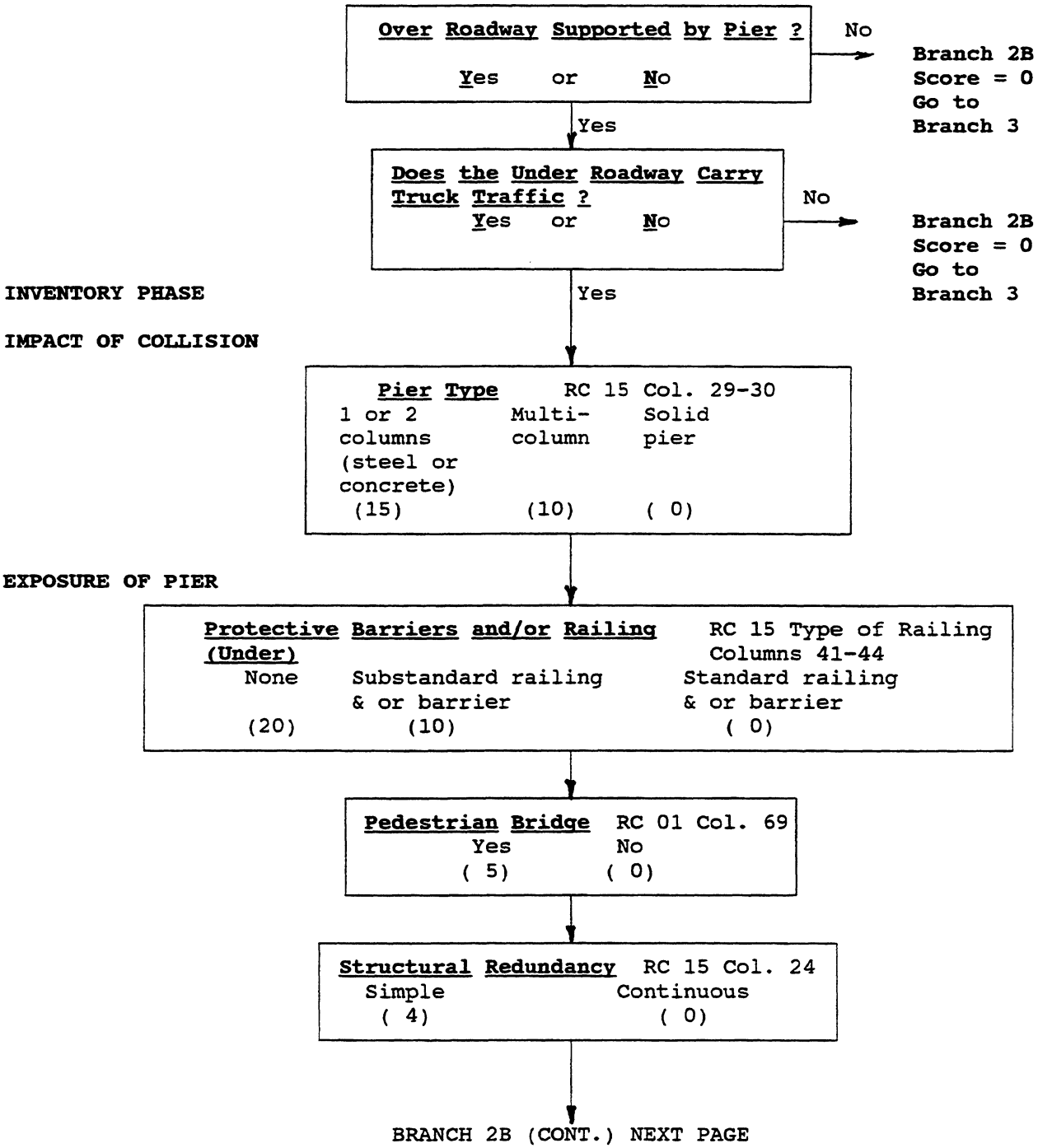
FIGURE 2.4

TRUCK UNDER BRIDGE COLLISION VULNERABILITY

BRANCH 2B - PIER SUSCEPTIBILITY TO TRUCK UNDER BRIDGE COLLISION

INVENTORY PHASE

IMPACT OF COLLISION



BRANCH 2B (CONT.) NEXT PAGE

FIGURE 2.4 (CONT.)

EXPOSURE OF PIER (CONT.)
CHARACTERISTICS OF TRAFFIC

Truck Traffic (Under) (ADTT)				RC 13 Cols 77-82
>5,000	>2,500 to 5,000	>1,000 to 2,500	>200 to 1000	200 & below
(15)	(12)	(8)	(4)	(0)

REGION REVIEW PHASE
EXPOSURE FACTORS

Horizontal Clearance (Edge of roadway to face Pier)		
< 30' w/o barrier or mound	< 30' w/ barrier or mound	> 30'
(8)	(4)	(0)

IMPACT OF COLLISION

Weight of Superstructure		
Light	Moderate	Heavy
(8)	(4)	(0)

Posted Speed Limit			
55-65 mph	40-50 mph	30-35 mph	<30 mph
(8)	(4)	(2)	(0)

CHARACTERISTICS OF TRAFFIC

Evidence of Previous Impact Damage	
Evidence or Documentation exists revealing prior collision impact damage	No evidence of prior impact damage exists
(15)	(0)

GEOMETRICS OF HIGHWAY

Orientation of Pier(s) with the Directon of Traffic Under the Bridge	
Skewed	Parallel
(4)	(0)

BRANCH 2B SUBTOTAL = _____

TOTAL SCORE BRANCH 2B = SUBTOTAL X 0.9 = _____

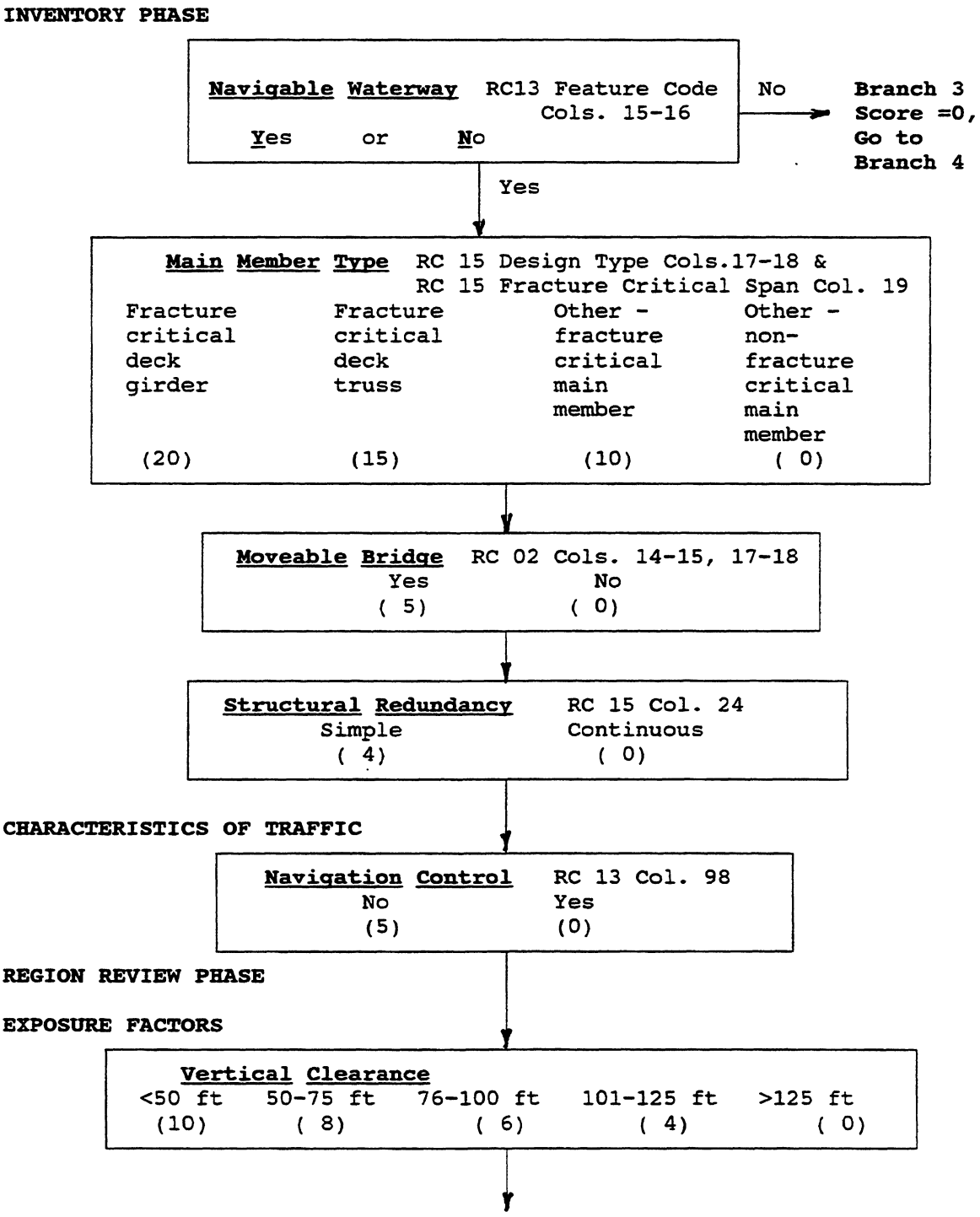
TOTAL SCORE BRANCH 2 = GREATER OF BRANCH 2A AND BRANCH 2B
= _____

Go to Branch 3

FIGURE 2.5

WATER VESSEL COLLISION VULNERABILITY

BRANCH 3A - SUPERSTRUCTURE VULNERABILITY TO WATER VESSEL COLLISION



BRANCH 3A (CONT.) NEXT PAGE

FIGURE 2.5 (CONT.)

IMPACT OF COLLISION

Type of Vessels Active in Waterway			
Ship	Inland waterway Barge	Special Vessels	Pleasure Craft Only
(10)	(5)	( )	(0) & Branch 3 Score = 0

Typical Cruising Speed in Vicinity of Bridge			
> 20 Knots	11-20 Knots	3-10 Knots	< 3 knots
(15)	(10)	(5)	(0)

CHARACTERISTICS OF TRAFFIC

Average Daily Traffic			
50 or more Vessels per day	21-49 Vessels per day	5-20 Vessels per day	< 5 Vessels per day
(20)	(15)	(10)	(0)

Evidence of Previous Impact Damage	
Evidence or Documentation exists revealing prior collision impact damage	No evidence of prior impact damage exists
(15)	(0)

WATERWAY CHARACTERISTICS

Water Depths	(Mean High Water to mudline)	
Unpredictable variation	Predictable variation	Constant
(10)	(5)	(0)

BRANCH 3A SUBTOTAL = _____

TOTAL SCORE BRANCH 3A = SUBTOTAL X 0.5 = _____

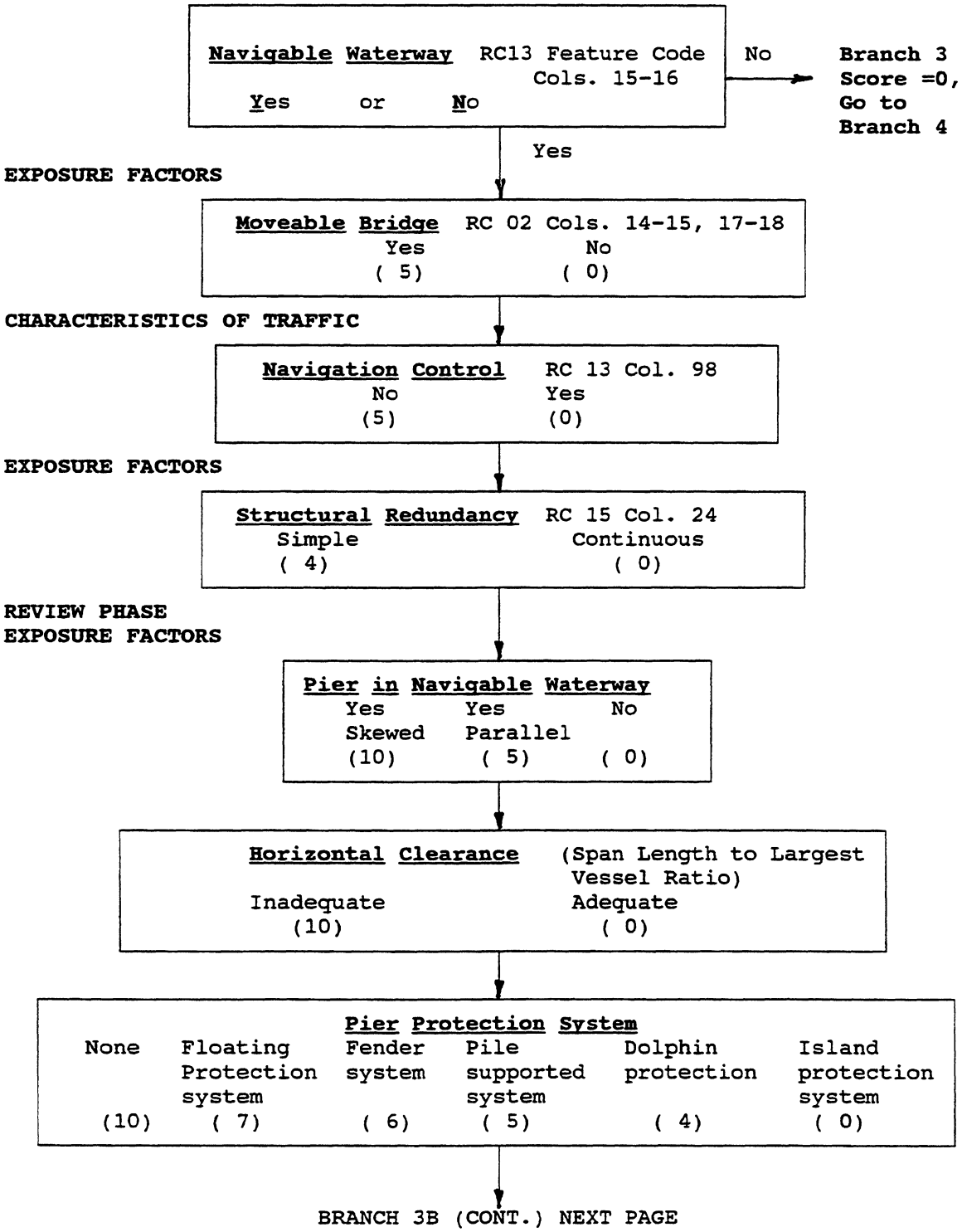
Go to Branch 3B

FIGURE 2.6

WATER VESSEL COLLISION VULNERABILITY

BRANCH 3B - PIER VULNERABILITY TO WATER VESSEL COLLISION

INVENTORY PHASE



BRANCH 3B (CONT.) NEXT PAGE

FIGURE 2.6 (CONT.)

IMPACT OF COLLISION

Type of Vessels Active in Waterway			
Ship	Inland waterway Barge	Other	Special
(10)	(5)	(0)	( )

Typical Cruising Speed in Vicinity of Bridge			
> 20 Knots	11-20 Knots	3-10 Knots	< Knots
(15)	(10)	(8)	(6)

CHARACTERISTICS OF TRAFFIC

Average Daily Traffic			
50 or more Vessels per day	21-49 Vessels per day	5-20 Vessels per day	< 5 Vessels per day
(20)	(15)	(10)	(0)

Evidence of Previous Impact Damage	
Evidence or Documentation exists revealing prior collision impact damage	No evidence of prior primary impact damage
(15)	(0)

WATERWAY CHARACTERISTICS

Channel Layout		
Poor	Fair	Good
(10)	(5)	(0)

Water Currents		
Strong cross currents common	Moderate cross currents common	Little or no cross Current
(6)	(3)	(0)

BRANCH 3B SUBTOTAL = _____

TOTAL SCORE BRANCH 3B = SUBTOTAL X 0.6 = _____

TOTAL SCORE BRANCH 3 = GREATER OF BRANCH 3A AND BRANCH 3B
=
_____

Go to Branch 4

FIGURE 2.7

TRAIN UNDER BRIDGE COLLISION VULNERABILITY

BRANCH 4A - SUPERSTRUCTURE VULNERABILITY TO TRAIN UNDER BRIDGE COLLISION

INVENTORY PHASE

Feature Under is a Railroad — RC 13 Cols. 15-16

Yes or No

No → **Branch 4 Score = 0, Highest Branch Score ?**

Yes

EXPOSURE FACTORS

Main Member Type — Design Type RC 15 Col. 17-18 & Fracture Critical Span RC 15 Col. 19

Fracture critical deck girder	Fracture critical deck truss	Other - fracture critical main member	Other - non-fracture critical main member
(20)	(15)	(10)	(0)

Vertical Clearance — RC 13 Cols. 94-97

<20'	20' to 20'-11"	21' to 22'	>22' & greater
(6)	(4)	(2)	(0)

Structural Redundancy — RC 15 Col. 24

Simple	High
(4)	(0)

REVIEW PHASE

Evidence of Previous Impact Damage

Evidence or Documentation exists revealing prior collision impact damage	No evidence of prior primary impact damage exists
(15)	(0)

BRANCH 4A SUBTOTAL = _____

TOTAL SCORE BRANCH 4A x 0.9 = _____

Go to Branch 4B

FIGURE 2.8

TRAIN UNDER BRIDGE COLLISION VULNERABILITY

BRANCH 4B - PIER VULNERABILITY TO TRAIN COLLISION

INVENTORY PHASE

RC 13 Cols. 15-16
Feature Under is a Railroad
Yes or No

No → **Branch 4 Score = 0, Highest Branch Score ?**

Yes

EXPOSURE FACTORS

Structural Redundancy RC 15 Col. 24

Simple	Continuous
(4)	(0)

REGION REVIEW PHASE

Horizontal Clearance

<10'	10'-15'	16'-20'	>20'
(6)	(4)	(2)	(0)

Crashwall

Not Present and Required	Present & Inadequate	Present & Adequate or Not Required
(10)	(4)	(0)

Evidence of Previous Impact Damage

Evidence or Documentation exists revealing prior collision impact damage	No evidence of prior impact damage exists
(15)	(0)

BRANCH 4B SUBTOTAL = _____

TOTAL SCORE BRANCH 4B = SUBTOTAL X 1.1 = _____

TOTAL SCORE BRANCH 4 = GREATER OF BRANCH 4A AND BRANCH 4B
= _____

CLASSIFICATION SCORE = HIGHEST SCORE OF BRANCHES 1-4
= _____

SECTION 3 RATING

3.1 General

- The Vulnerability Rating process is common to all six identified BSA failure modes and it is intended to provide a uniform measure of a structure's vulnerability to failure on the basis of the likelihood of a failure occurring and the consequences of a failure.

There are six possible vulnerability ratings as shown in Table 3.1. The six ratings indicate the type of corrective actions needed to reduce the failure vulnerability of a bridge and the urgency in which these actions should be implemented. Definitions are found in Appendix A.

TABLE 3.1 Vulnerability Rating Descriptions

RATING	DESCRIPTION
1	Safety Priority
2	Safety Program
3	Capital Program
4	Inspection Program
5	No Action
6	Not Applicable

Figure 3.1 shows an overview of the rating process and a detailed description is found in Section 3.2. Bridges may be rated without the use of these guidelines, however complete documentation justifying the rating must be submitted to the Structures Division.

3.2 Rating Procedures

- The vulnerability rating process is similar to the classifying process, in that scores are assigned to evaluate the likelihood and consequence of a failure and then these rating scores are combined, as shown in equation 3.1, to determine the vulnerability rating score.

$$\underset{\text{Rating Score}}{\text{Vulnerability}} = \underset{\text{Score}}{\text{Likelihood}} + \underset{\text{Score}}{\text{Consequence}} \quad (3.1)$$

The vulnerability rating (1 through 6) is determined using the rating score ranges shown in Table 3.2. Overlapping ranges are provided to allow the evaluator some discretion in choosing the appropriate rating. A rating outside the recommended ranges may be used, however complete documentation must be submitted to the Structures Division.

TABLE 3.2 Vulnerability Rating Score Ranges

RATING	SCORING RANGE
1	> 15
2	13 - 16
3	9 - 14
4	< 15
5	< 9
6	---

The likelihood and consequence scores are weighted equally in the rating equation. The likelihood score is determined using the results of the classifying process and, the consequence score is determined on the basis of the type of failure which is anticipated and the public exposure to that failure.

Figure 3.2 can be used as a worksheet for completing the ratings and as a summary sheet for the results. Detailed descriptions of the criteria for evaluating the likelihood and consequence of a failure are found in Sections 3.2.1 and 3.2.2 respectively.

Bridges which are not vulnerable to a particular failure mode should be rated 6, for that mode. For instance, a multi-girder bridge over a non-navigable waterway is not vulnerable to collision impact damage. In these instances the vulnerability rating score can be disregarded and a rating of 6 assigned to the structure.

3.2.1 Likelihood of a Failure

- The likelihood of failure score is determined using the results of the classifying process. If available, the results of a detailed engineering analysis should also be used to supplement the results of the classifying process. Table 3.3 provides scores which should be assigned to the different vulnerability categories.

The vulnerability classes (HIGH, MEDIUM AND LOW) the same as previously defined in Table 2.3 of the classifying step. If there is no vulnerability to a particular failure mode the Vulnerability Rating Score shall be zero. The likelihood score determined from Table 3.3 should be used in equation 3.1 to determine the vulnerability rating score.

TABLE 3.3 Likelihood of Failure Scores

VULNERABILITY CLASS	LIKELIHOOD SCORE
HIGH	10
MEDIUM	6
LOW	2
NOT VULNERABLE	0

3.2.2 Consequence of Failure - The consequence of failure is evaluated on the basis of the type of failure the bridge is prone to, and a measure of the exposure to the public that a failure would cause. The type of failure that the bridge is prone to, is determined by evaluating what effect a collision impact damage failure of a primary member would have on a span. The result of this evaluation will be a consequence score determined as shown in equation 3.2. This score is used in equation 3.1 to determine the vulnerability rating score.

$$\text{Consequence Score} = \text{Failure Type Score} + \text{Exposure Score} \qquad (3.2)$$

Descriptions of the failure type and value criteria evaluation procedures follow.

a. **Failure Type** - Failure type is a measure of the way in which a bridges fails. When evaluating this parameter, it is assumed that a failure has or will take place. The task of the rating engineer is to decide what the failure would look like. That is, will it be a sudden and complete collapse with potentially catastrophic consequences, or will it be a partial or localized failure that may or may not affect the serviceability of the structure.

Three failure types have been defined and are shown in Table 3.4.

TABLE 3.4 FAILURE TYPE DEFINITIONS

Catastrophic - The structure is vulnerable to a sudden and complete collapse of a superstructure span or spans. This failure may be the result of a partial or total failure of either the superstructure or the substructure. A failure of this type would endanger the lives of those on or under the structure.

Partial Collapse - The structure is vulnerable to major deformation or discontinuities of a span (which would result in loss of service to traffic on or under the bridge.) This failure may be the result of tipping or tilting of the substructure causing deformations in the superstructure. A failure of this type may endanger the lives of some of those crossing on or under the structure.

Structural Damage - The structure is vulnerable to localized failures. This failure may be the result of excessive deformation or cracking in the primary superstructure or substructure members of the bridge. A failure of this type may be unnoticed by the traveling public but would require repair once it is discovered.

Collision impact damage failures will generally involve some level of distortion or fracturing of the primary structural members on a bridge. Some factors which should be considered to evaluate the failure type are listed below. Combinations of these and other factors will determine the potential failure type of a structure.

other factors will determine the potential failure type of a structure.

- Redundancy of the Superstructure (Internally and Externally)
- Critical member location
- Simple span vs Continuous spans
- Bridge type
- Span length
- Support conditions
- Abutments and Piers:

Type	Size
Height	Foundations
Bearing types	Seat widths

Rating scores assigned for the different failure types. Table 3.5 shows the scores are used in equation 3.2 to determine the consequence of failure score.

TABLE 3.5 Failure Type Rating Scores

Failure Type	Score
Catastrophic	5
Partial Collapse	3
Structural Damage	1

b. Exposure - The exposure parameter is a measure of the affect that a failure of a structure will have on the users of the bridge and the highway network. The exposure score is determined on the basis of the traffic volume on the bridge and the functional classification of the highways both carried and crossed by the bridge. The score is determined as shown in equation 3.3. This score is used in equation 3.2 to determine the consequence score.

Exposure = Traffic Volume + Functional Classification (3.3)
Score Score Score

Rating scores for traffic volume and functional classification are assigned as shown in Table 3.6. These scores are used in equation 3.3.

TABLE 3.6 Exposure Rating Scores

Traffic Volume		Functional Classification	
AADT	Score		Score
> 25,000	2	Interstate & Freeway	3
4,000 - 25,000	1	Arterial	2
< 4,000	0	Collector	1
		Local Road & Below	0

The functional classifications are based on the definitions listed in the BIIS manual[2]. Both the feature carried and the feature intersected should be evaluated and the highest score used.

Figure 3.1

Vulnerability Rating Procedure

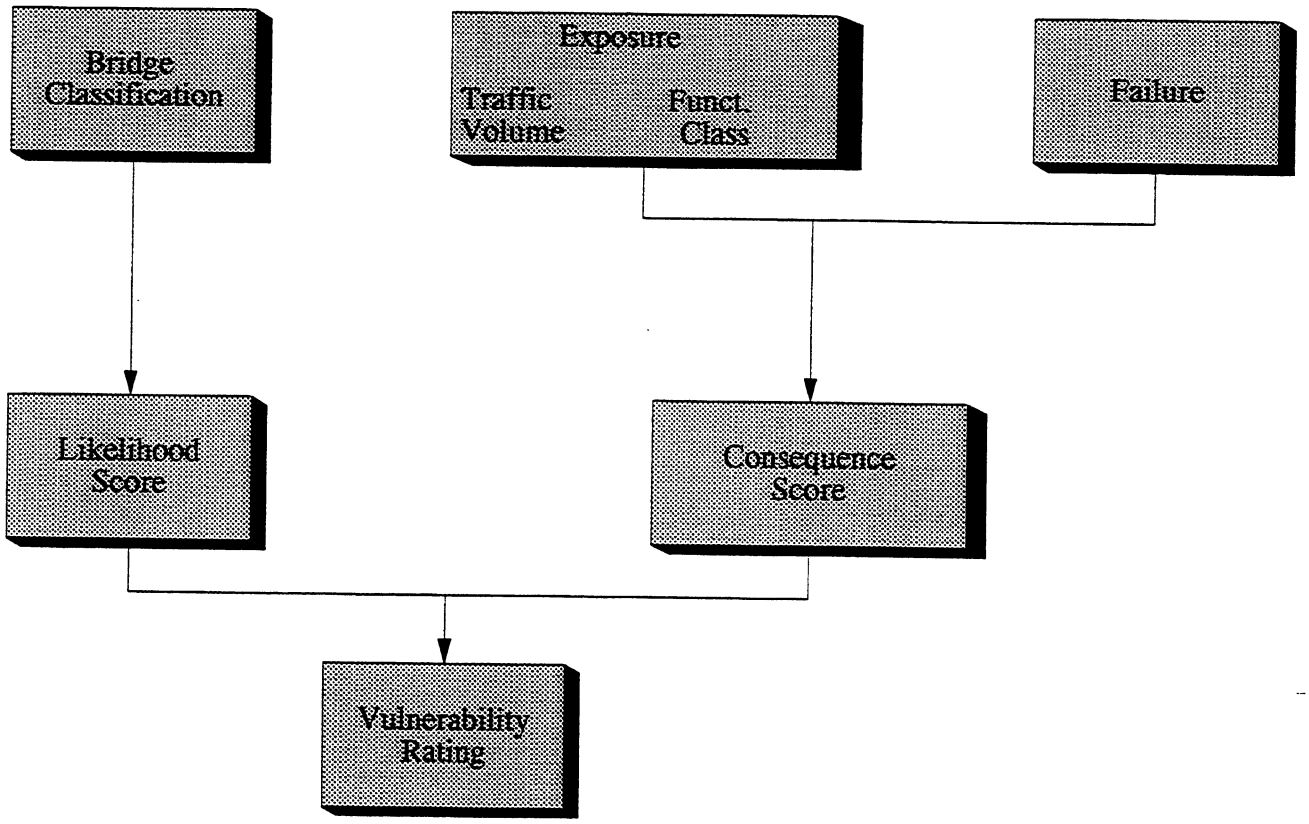


Figure 3.2

Collision Rating Process

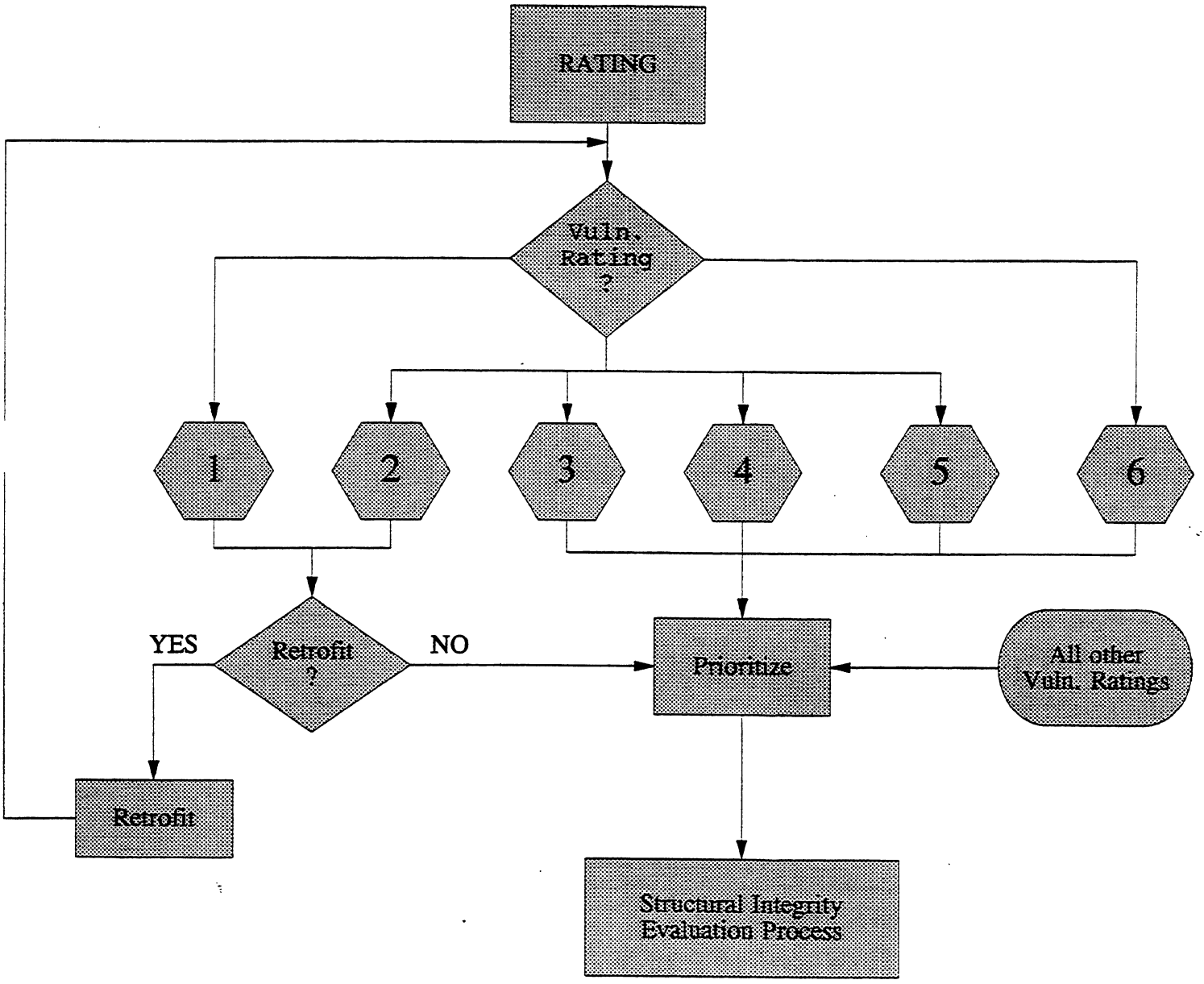


FIGURE 3.3

VULNERABILITY RATING SUMMARY SHEET

DATE _____

RC ___ BIN _____ NAME _____

CARRIED _____ CROSSED _____

LIKLIHOOD SCORE:

Vulnerability Class

HIGH	= 10	
MEDIUM	= 6	
LOW	= 2	_____
NOT VULNERABLE	= 0	

CONSEQUENCE SCORE:

Failure Type

Catastrophic	= 5	
Partial Collapse	= 3	_____
Structural Damage	= 1	

Exposure

Traffic Volume Score

> 25,000 AADT	= 2	
4,000 - 25,000 AADT	= 1	_____
< 4,000 AADT	= 0	

Functional Classification Score

Interstate & Freeway	= 3	
Arterial	= 2	
Collector	= 1	_____
Local Road & Below	= 0	

TOTAL = _____

VULNERABILITY RATING SCORE:

Rating		
> 15	1	Safety Priority
13 - 16	2	Safety Program
9 - 14	3	Capital Program _____
< 15	4	Inspection Program
< 9	5	No Action
----	6	Not Applicable

Revised June 1996

SECTION 4 REFERENCES

1. A. M. Shirolé and R. C. Holt, Planning for a Comprehensive Bridge Safety Assurance Program. TRB R90, Vol. 1, TRB, National Research Council, Washington, D.C., 1991, pp. 39-50.

2. "New York State Department of Transportation Bridge Inventory Manual", New York State Department of Transportation, Albany, NY, December 1990.

APPENDIX A

VULNERABILITY RATING SCALE

1. **SAFETY PRIORITY ACTION** - This rating designates a vulnerability to failure resulting from loads or events that are likely to occur. Remedial work to reduce the vulnerability must be given immediate priority.

2. **SAFETY PROGRAM ACTION** - This rating designates a vulnerability to failure resulting from loads or events that may occur. Remedial work to reduce the vulnerability does not need immediate priority but waiting for Capital Program action would be too long.

3. **CAPITAL PROGRAM ACTION** - This rating designates a vulnerability to failure resulting from extreme loads or events that are possible but not likely. This risk can be tolerated until a normal capital construction project can be implemented.

4. **INSPECTION PROGRAM ACTION** - This rating designates a vulnerability to failure presenting minimal risk providing that anticipated conditions or loads on structure do not change. Unexpected failure can be avoided during the remaining life of the structure by performing the normal scheduled bridge inspections with attention to factors influencing the vulnerability of the structure.

5. **NO ACTION** - This rating designates a vulnerability to failure which is less than or equal to the vulnerability of a structure built to the current design standards. Likelihood of failure is remote.

6. **NOT APPLICABLE** - This rating designates there is no exposure to a specific type of vulnerability.

APPENDIX B

COLLISION VULNERABILITY ASSESSMENT

Reg. ___ County____ BIN_____Carried_____Crossed_____

By:_____ Date_____ Year Built _____

SCORES SHOWN IN ( )	Span Number					
BRANCH 1: TRUCK ON BRIDGE COLLISION VULNERABILITY						
A. BRIDGE TYPE: IS THE BRIDGE TYPE A THRU GIRDER OR A TRUSS? Yes (1) No(0) If NO, Branch 1 Total Score = 0						
B. TRUCK TRAFFIC: DOES THE ROADWAY CARRY TRUCK TRAFFIC? Yes (1) No (0) If NO, Branch 1 Total Score = 0						
C. LANES OF TRAFFIC (ON): > 4 (6) 4 (4) 3 (2) 2 (1) 1 (0)						
D. WIDTH OF TRAVEL LANE (ON): < 10' (5) 10' TO 11' (3) > 11' TO 12' (1) >12' (0)						
E. MIN. VERTICAL CLEARANCE (ON): <13'-0" TO 13'-11" (3) 14'-0" TO 14'-11" (2) 15'-0" TO 15'-11" (1) 16'-0" AND GREATER (Or no overhead bracing) (0)						
F. PROTECTIVE BARRIERS: NONE (20) SUBSTANDARD BARRIER (10) STANDARD BARRIER (0)						
G. ADTT (ON): >5,000 (15) >2,500 TO 5,000 (12) >1,000 TO 2,500 (8) >200 TO 1,000 (4) 200 & BELOW (0)						
H. BR. WIDTH VS. HWY. WIDTH: SEVERE NECKING, >10 FT (10) MOD. NECKING, 5-10 FT (6) MINOR NECKING, <5 FT (2) NO CHANGE (0)						
I. APPROACH ROADWAY ASSESSMENT: SUBSTANTIAL SPEED REDUCTION REQD. (10) MINOR SPEED RED. REQD. (5) NO SPEED REDUCTION REQUIRED (0)						
J. PRES. WEARING SURFACE: STEEL GRATING - OPEN OR FILLED (5) TIMBER (3) OTHER SURF. (0)						
K. WEARING SURFACE CONDITION RATING: <3 (5) 3 OR HIGHER (0)						
L. LIGHTING (ON): NO LIGHTING (2) LIGHTING (0)						
M. DESIGN TYPE: LIGHT TRUSS (10) HEAVY TRUSS (4) THRU GIRDER (0)						
N. POSTED LOAD: NOT POSTED (8) 27-36 TONS (6) 20-26 TONS (4) 12-19 TONS (3) 7-11 TONS (2) 3-6 TONS (0)						
O. POSTED SPEED LIMIT: >55 MPH (8) 40-50 MPH (4) 30-35 MPH (2) <30 MPH (0)						
P. PREV. IMPACT DAMAGE: EVIDENCE OR DOCUMENTATION EXISTS (15) NO EVIDENCE EXISTS (0)						
Q. VC WARNING SIGNS: NOT PROVIDED (2) PROVIDED BUT NOT ADEQUATE (1) PROVIDED OR NOT REQD. (0)						
R. HC WARNING SIGNS: NOT PROVIDED (2) PROVIDED BUT NOT ADEQUATE (1) PROVIDED OR NOT REQD. (0)						
S. ELEV. CURB OR SDWLK: NO ELEV. CURB OR SDWLK (4) ELEV. CURB /SDWLK EXISTS (0)						
TOTAL SCORE - BRANCH 1 x 0.8						
BRANCH 2A: SUPERSTRUCTURE VULN. TO TRUCK UNDER BRIDGE COLLISION						
A. UNDER ROADWAY FEATURE: IS FEATURE UNDER A ROADWAY? Yes (1) No(0) If NO, Branch 2 Total Score = 0						
B. TRUCK TRAFFIC: DOES UNDER RDWY CARRY TRUCK TRAFFIC? Yes (1) No (0) If NO, Branch 2 Total Score = 0						
C. MAIN MEMBER TYPE: FRACTURE CRITICAL DECK GIRDER (20) FC DECK TRUSS (15) OTHER FC MAIN MEMBER (10) OTHER NON-FC MAIN MEMBER (0)						
D. PEDESTRIAN BRIDGE: YES (5) NO (0)						
E. MIN. VERTICAL CLEARANCE (UNDER): <13'-0" TO 13'-5" (6) 13'-6" TO 13'-11" (4) 14'-0" TO 14'-5" (3) 14'-6" TO 15-3" (2) 15'-4" TO 16'-0" (1) >16'-0" (0)						
F. STRUCTURAL REDUNDANCY: SIMPLE (4) CONTINUOUS (0)						
G. ADTT (UNDER): >5,000 (15) >2,500 TO 5,000 (12) >1,000 TO 2,500 (8) >200 TO 1,000 (4) 200 & BELOW (0)						
H. LIGHTING (UNDER): NO LIGHTING (3) LIGHTING (0)						
I. POSTED SPEED LIMIT: 55 MPH (8) 40-50 MPH (4) 30-35 MPH (2) <30 MPH (0)						
J. PREV. IMPACT DAMAGE: EVIDENCE OR DOC. EXISTS (15) NO EVIDENCE EXISTS (0)						
K. VC WARNING SIGNS: NOT PROVIDED (4) PROVIDED BUT NOT ADEQUATE (2) PROVIDED OR NOT REQD. (0)						
TOTAL SCORE - BRANCH 2A						
BRANCH 2B: PIER VULN. TO TRUCK UNDER BRIDGE COLLISION						
A. PIER SUPPORT: IS OVER RDWY SUPPORTED BY A PIER? Yes (1) No (0), If NO, Branch 2B Total Score = 0						
B. TRUCK TRAFFIC: DOES UNDER RDWY CARRY TRUCK TRAFFIC? Yes (1) No (0) If NO, Branch 2 Total Score = 0						
C. PIER TYPE: 1 OR 2 COL. (STEEL OR CONC.) (15) MULTI-COL. (10) SOLID PIER (0)						
D. PROTECTIVE BARRIERS: NONE (20) SUBSTANDARD BARRIER (10) STANDARD BARRIER (0)						
E. PEDESTRIAN BRIDGE: YES (5) NO (0)						
F. STRUCTURAL REDUNDANCY: SIMPLE (4) CONTINUOUS (0)						
G. ADTT (UNDER): >5,000 (15) >2,500 TO 5,000 (12) >1,000 TO 2,500 (8) >200 TO 1,000 (4) 200 & BELOW (0)						

COLLISION VULNERABILITY ASSESSMENT (CONTINUED)

Reg. ___ County____ BIN_____Carried_____Crossed_____

By:_____ Date_____ Year Built _____

SCORES SHOWN IN ( )	Span Number					
H. HORIZ. CLEARANCE (EDGE OF ROADWAY TO FACE PIER): <30' W/O BARRIER OR MOUND (8) <30' WITH BARRIER OR MOUND (4) >30' (0)						
I. WEIGHT OF SUPERSTRUCTURE: LIGHT (8) MODERATE (4) HEAVY (0)						
J. POSTED SPEED LIMIT: 55 MPH (8) 40-50 MPH (4) 30-35 MPH (2) <30 MPH (0)						
K. PREV. IMPACT DAMAGE: EVIDENCE OR DOC. EXISTS (15) NO EVIDENCE EXISTS (0)						
L. ORIENT. OF PIER(S) WITH THE DIR. OF TRAFFIC UNDER THE BRIDGE: SKEWED (4) PARALLEL (0)						
TOTAL SCORE - BRANCH 2B x 0.9						
TOTAL SC ORE BRANCH 2 = GREATER OF BRANCH 2A AND 2B						
BRANCH 3A: SUPERSTRUCTURE VULNERABILITY TO WATER VESSEL COLLISION						
A. NAVIGABLE WATERWAY: IS STRUCTURE OVER A NAVIGABLE WATERWAY? Yes (1) No (0) If NO, Branch 3 Total Score = 0						
B. MAIN MEMBER TYPE: FRACTURE CRITICAL DECK GIRDER (20) FC DECK TRUSS (15) OTHER FC MAIN MEMBER (10) OTHER NON-FC MAIN MEMBER (0)						
C. MOVABLE BRIDGE: YES (5) NO (0)						
D. STRUCTURAL REDUNDANCY: SIMPLE (4) CONTINUOUS (0)						
E. NAVIGATION CONTROL: NO (5) YES (0)						
F. VERTICAL CLEARANCE: <35' (10) 35-50' (8) 50-75' (6) 76-100' (4) 101-125' (2) > 125' (0)						
G. TYPE OF VESSELS ACTIVE IN WATERWAY: SHIP (10) INLAND WATERWAY BARGE (5) SPECIAL VESSELS ( ) PLEASURE CRAFT ONLY (0) , and Branch 3 Total Score =0						
H. TYP. CRUISING SPEED OF SHIPS/BARGES IN VICINITY OF BRIDGE : > 20 KNOTS (15) 11-20 KNOTS (10) 3-10 KNOTS (5) < 3 KNOTS (0)						
I. AVG. DAILY SHIP & BARGE TRAFFIC: >= 50 VESSELS PER DAY (20) 21-49 (15) 5-20 (10) <5 (0)						
J. PREV. IMPACT DAMAGE: EVIDENCE OR DOC. EXISTS (15) NO EVIDENCE EXISTS (0)						
K. WATER ELEVATION (MEAN HIGH WATER TO ORDINARY WATER): LARGE VARIATION (10) MODERATE VARIATION (5) LITTLE (0)						
TOTAL SCORE - BRANCH 3A x 0.5						
BRANCH 3B: PIER VULNERABILITY TO WATER VESSEL COLLISION						
A. NAVIGABLE WATERWAY: IS STRUCTURE OVER A NAVIGABLE WATERWAY? Yes (1) No (0) If NO, Branch 3 Total Score = 0						
B. MOVABLE BRIDGE: YES (5) NO (0)						
C. NAVIGATION CONTROL: NO (5) YES (0)						
D. STRUCTURAL REDUNDANCY: SIMPLE (4) CONTINUOUS (0)						
E. PIER IN NAV. WATERWAY: YES - SKEWED (10) YES - PARALLEL (5) NO (0), and Branch 3B Total Score = 0						
F. TYPE OF VESSELS ACTIVE IN WATERWAY: SHIP (10) INLAND WATERWAY BARGE (5) SPECIAL VESSELS ( ) PLEASURE CRAFT ONLY (0) , If NO, Branch 3 Total Score = 0						
F. HORIZ. CLEAR. (SPAN WIDTH TO LARGEST VESSEL RATIO): INADEQUATE (10) ADEQUATE (0)						
G. PIER PROTECTION SYSTEM: NONE (10) FLOATING PROTECTION (7) FENDER SYSTEM (6) PILE SUPPORTED SYSTEM (5) DOLPHIN PROTECTION (4) ISLAND PROTECTION SYSTEM (0)						
H. TYPE OF VESSELS ACTIVE IN WATERWAY: SHIP (10) INLAND WATERWAY BARGE (5) SPECIAL VESSELS ( ) PLEASURE CRAFT ONLY (0) , If NO, Branch 3 Total Score = 0						
I. TYP. CRUISING SPEED OF SHIPS/BARGES IN VICINITY OF BRIDGE: > 20 KNOTS (15) 11-20 KNOTS (10) 3-10 KNOTS (5) < 3 KNOTS (0)						
J. AVG. DAILY VESSEL TRAFFIC: >= 50 VESSELS PER DAY (20) 21-49 (15) 5-20 (10) <5 (0)						
K. PREV. IMPACT DAMAGE: EVIDENCE OR DOC. EXISTS (15) NO EVIDENCE EXISTS (0)						
L. CHANNEL LAYOUT: POOR (10) FAIR (5) GOOD (0)						
M. WATER CURRENTS: STRONG CROSS CURRENTS COMMON (6) MOD. CROSS-CURRENTS (3) LITTLE OR NO CROSS-CURRENTS (0)						
TOTAL SCORE - BRANCH 3B x 0.6						
TOTAL SC ORE BRANCH 3 = GREATER OF BRANCH 3A AND 3B						

COLLISION VULNERABILITY ASSESSMENT (CONTINUED)

Reg. ___ County____ BIN_____Carried_____Crossed_____

By:_____ Date_____ Year Built _____

SCORES SHOWN IN ( )	Span Number					
BRANCH 4A: SUPERSTRUCTURE VULN. TO TRAIN UNDER BRIDGE COLLISION						
A. FEATURE UNDER: IS FEATURE UNDER A RAILROAD? Yes (1) No (0) If NO, Branch 4 Total Score = 0						
B. MAIN MEMBER TYPE: FRACTURE CRITICAL DECK GIRDER (20) FC DECK TRUSS (15) OTHER FC MAIN MEMBER (10) OTHER NON-FC MAIN MEMBER (0)						
C. VERTICAL CLEARANCE: < 20' (6) 20' TO 20'-11" (4) 21' TO 22' (2) >22' (0)						
D. STRUCTURAL REDUNDANCY: SIMPLE (4) CONTINUOUS (0)						
E. PREV. IMPACT DAMAGE: EVIDENCE OR DOC. EXISTS (15) NO EVIDENCE EXISTS (0)						
TOTAL SCORE - BRANCH 4A x 0.9						
BRANCH 4B: PIER VULNERABILITY TO TRAIN UNDER BRIDGE COLLISION						
A. FEATURE UNDER: IS FEATURE UNDER A RAILROAD? Yes (Y) No (N) If NO, Branch 4 Total Score = 0						
B. STRUCTURAL REDUNDANCY: SIMPLE (4) CONTINUOUS (0)						
C. HORIZONTAL CLEARANCE: <10' (6) 10' TO 15' (4) 16' to 20' (2) > 20' (0)						
D. CRASHWALL: NOT PRESENT AND REQD (20) PRESENT & INADEQUATE (4) PRESENT & ADEQUATE OR NOT REQD (0)						
E. PREV. IMPACT DAMAGE: EVIDENCE OR DOC. EXISTS (15) NO EVIDENCE EXISTS (0)						
TOTAL SCORE - BRANCH 4B x 1.1						
TOTAL SC ORE BRANCH 4 = GREATER OF BRANCH 4A AND 4B						
CLASSIFICATION SCORE = HIGHEST BRANCH SCORE						
VULNERABILITY CLASSIFICATION: > 40 HIGH (H) 25-55 MED. (M) <40 LOW (L)						
VULNERABILITY RATING						
LIKLIHOOD SCORE (Based on Vuln. Class.) HIGH (10) MEDIUM (6) LOW (2) NOT VULN. (0)						
CONSEQUENCE SCORE (Based on Failure Type and Exposure Score)						
FAILURE TYPE CATASTROPHIC (5) PARTIAL COLLAPSE (3) STRUCTURAL DAMAGE (1)						
EXPOSURE						
TRAFFIC VOLUME SCORE > 25,000 AADT (2) 4,000 - 25,000 AADT (1) <4,000 AADT (0)						
FUNCT. CLASS. SCORE INTERSTATE (3) ARTERIAL (2) COLLECTOR (1) LOCAL (0)						
VULNERABILITY RATING SCORE						
VULNERABILITY RATING: >15 (1) 13-16 (2) 9-14 (3) <15 (4) <9 (5) --- N/A (6) (Based on Highest Vuln. Rating Score)						